Iron and Steel Engineer

Established 1907 as Proceedings of A. I. & S. E. E.

J. F. KELLY, Editor

CONTENTS

Vol. V April, 1928 No. 4

Coming Meetings and Papers II

Editorials III

Effect of Grounding on Telephone Interference—
By J. J. Pilliod 147

Theory of Grounding—By F. C. Hanker 155

The Effect of Grounded Neutral on the Efficiency of Lightning Protection Equipment—By K. B. McEachron 160

Experience of a Public Utility With Grounded Neutral—
By George S. Humphrey 163

The Effect of Grounding on the Reliability of Relay Operation—By E. A. Hester and B. M. Jones 166

Experiences in the Steel Industry With the Grounded Neutral—By A. C. Cummins 168

Cold Rolling of Strip Steel—By H. C. Uhl 171

Discussions on Grounded Neutral—
By Elbert Lewis, E. C. Marshall, R. S. Shoemaker, W. E. Miller, R. D. Evans, E. G. Merrick 178

Items of Interest 180

(List of Advertisers IV)

Published Monthly by

Association of Iron and Steel Electrical Engineers

BOARD OF DIRECTORS—1928

A. J. STANDING, President, Bethlehem Steel Company, Bethlehem, Pa.

C. S. PROUDFOOT, 1st V. Pres.—United States Ferro Alloys Corp., Niagara Falls, N. Y.
F. W. CRAMER, 2nd Vice Pres.—Bethlehem Steel Co., Johnstown, Pa.
S. S. WALES, Past President—Carnegie Steel Co., Pittsburgh, Pa.
GEORGE H. SCHAEFFER, Past Pres.—Carpenter Steel Co., Reading, Pa.
JAMES FARRINGTON, Treasurer—Wheeling Steel Corp., Steubenville, O.
A. G. PLACE, Secy.—Youngstown Sheet & Tube Co., Youngstown, O.
R. S. SHOEMAKER, Director at Large, American Rolling Mills, Middletown, O.
W. J. HARPER, Director—Donner Steel Co., Buffalo, N. Y.
JOHN A. OARTEL, Director—Carnegie Steel Co., Pittsburgh, Pa.
ELBERT LEWIS, Director—Illinois Steel Co., South Chicago, Ill.
W. W. GARRET, Director—Tennessee Coal, Iron & Railroad Co., Fairfield, Ala.
A. L. REICHERT, Director—Bourne Fuller Co., Cleveland, Ohio.
E. FRIEDLAENDER, Honorary Director—Pittsburgh, Pa.

JOHN F. KELLY, Managing Director—Empire Building, Pittsburgh, Pa.

Entered as second-class matter January 25th, 1924, at Pittsburgh, Pa., under the Act of March 3rd, 1879.
Subscription Price $5.00 per Year. Single Copy 50c.

COMING MEETINGS AND PAPERS

CHICAGO DISTRICT SECTION

Tuesday, April 24, 1928	**Electric Power Club**	**30 North Dearborn St., Chicago, Ill.**

"WATER COOLED FURNACES," by Mr. Martin Frisch, Combustion Engineering Corporation, New York, N. Y.

BIRMINGHAM DISTRICT SECTION

Saturday, April 28th, 1928

"WASTE HEAT BOILERS," by J. B. Crane, Engineer, Ladd Water Tube Boiler Division, International Combustion Engineering Company, New York, N. Y.

CLEVELAND DISTRICT SECTION

Friday, April 20th, 1928

"ARC WELDING IS SELLING STEEL," by J. F. Lincoln, Lincoln Electric Company, Cleveland, Ohio.

In connection with this technical session, there will be an inspection trip to the plant of the Cleveland Crane & Engineering Company at Wickliffe, Ohio. Upon completion of this inspection, the visitors will be escorted to the plant of the Lincoln Electric Company, Cleveland, Ohio, where another inspection will take place, followed by the paper by Mr. Lincoln. While this meeting is being held under the auspices of the Cleveland District Section, all members of other sections are cordially invited to be present.

PHILADELPHIA DISTRICT SECTION

Friday or Saturday, May 4th or 5th, 1928

Inspection Trip to Conowingo Plant of Philadelphia Electric Company. At the time of going to press, a definite date had not been set for this trip. For complete details, please refer to the notice which is being sent out by our Philadelphia District Section.

IRON AND STEEL EXPOSITION

June 25th to 28th, 1928	**Hotel Stevens**	**Chicago, Ill.**

Reports and Papers will be delivered on the following subjects: "Electric Heat," "Electrical Developments," "Electric Welding," "Standardization," "High Tension Practices," "Motor Driven Rollers," "Selection of Motors for Main Drives of Strip and Skelp Mills," "Selection of Motors for Main Drives of Merchant, Bar and Rod Mills," "Fuel Savings Conference," "Insulation of Open Hearth Checkers," "Boiler Pressures Above 350 Pounds," "Factors Governing the Purchase of Coal," Anti-Friction Bearings for Roll Necks," "Anti-Friction Bearings for Motors," "Anti-Friction Bearings for Auxiliaries" and Inspection Trips.

EDITORIAL

ARC WELDING AND THE NEW MARKET FOR ROLLING MILL SHAPES

By J. F. LINCOLN*

THE fusion of metals with the Electric Arc is not old as age is counted in the realm of history or natural science, but it is old as time is measured in this modern industrial age.

Commercially, practical welders have been recognized production tools for several years and have broadened their scope immeasurably since their introduction. Today they are employed for thousands of purposes to which they were absolutely foreign five or ten years ago. It is not an exaggeration to say that in some fields of manufacture they have completely revolutionized former practices.

The electric arc welder and the standard products of the rolling mill go hand in hand. Without the latter the former could never be what it is. For it is by utilizing mild steel forms and welding them into the requisite shapes that producers of machinery and equipment are effecting the greatest production economies that have been realized in years. In case that statement may need clarification, let us say quite bluntly that welded steel is replacing castings and in so doing it is making vast manufacturing economies.

Strange as it may seem, steel men as a whole have shown less interest in the development of arc welding than its importance to them deserves. It may be that the facts have never been put before them heretofore. If such is the case they will find the figures we are about to cite worthy of their study.

The broadest use for the electric arc welder is in providing a means of fabricating mild steel shapes into structures that will replace castings. The Department of Commerce report for 1927 on 133 malleable iron foundries shows a tonnage of 631,388 tons. That report covers about two-thirds of all the malleable iron foundries. A conservative estimate by authorities on the subject, places the total tonnage at 930,000 tons.

The Department of Commerce report for 1927 on 129 steel foundries shows a tonnage of 964,715 tons. In this class also the Department of Commerce report is incomplete. The probable tonnage is in the vicinity of 1,400,000 tons.

The foundry pig iron tonnage for 1927 was 5,504,419 tons. The approximate sum of these three classes totals the gigantic figure of 7,834,419 tons, or a normal yearly expenditure of $705,097,710 at the most conservative estimate.

The sales problem of this age is the cultivation of new markets and the broadening of old, and the steel mills are not exempt from its necessities. In witness of that fact there is the statement on tonnage for last year, which indicates there was an appreciable decline, which in some of the larger mills was as great as 20%. In view of these facts, the steel industry's apathy toward electric arc welding is the more incomprehensible. Approximately 7,834,419 tons of castings were produced—and 90% of them could have been made better and more economically from rolling mill stock. Is that a market worth cultivating? It seems to us it is.

The Electrical Companies have quite naturally been doing everything to forward a country wide interest in welding. They have been engaged in intensive engineering research work and have given their assistance in the solution of every welding problem that has come to them. But there is still much to be done in the compiling of data and experience. And, it is only by placing welded steel on the firm scientific basis it deserves that its widest adoption can be accomplished.

In this day in which we live, manufacturing success depends very greatly on the manufacturer's flexibility of mind and his willingness to reject the old method when a new and better is advanced. It is safe to say that at the present time there is no best method of procedure, in the building of any sort of machinery, which was also the best method of five years ago. Progress is rapid, so rapid in fact that new equipment is antiquated, inefficient and uneconomical long before its useful life is spent. New models of almost every tool appear at least once a year, some oftener than that. When made of castings a staggering amount of working capital is consumed in these changes.

To alter a foundry built machine it is necessary to make expensive working drawings, build costly patterns, pour castings and perform the machining and assembly operations before the new model can be tried or tested. That is an expense that, in a large part, is not incurred in making a change in an arc welded structure. To improve a welded design all that is required is a new set of drawings; or in case the job is done with fixtures, a revised set of jigs. The value of that advantage cannot be over stressed, for many manufacturers are finding the burden of the constant change demanded by the American public to be destructive of profit, because it compounds overhead costs and carrying charges.

Manufacturers are replacing castings with welded steel for three main reasons. The first is that of economy. In brief the saving is this: Rolling mill shapes cost less than 2½c a pound against cast iron at 4½c.

The second reason for the utilization of arc welded steel is its superior strength and stiffness. Weight for weight steel is six times as strong in tension as cast iron, and has an advantage of two and one-half to one in stiffness. This of course means that proportionate reductions in weight can be made.

The third reason is the really marvelous manufacturing flexibility that is acquired by the introduction of arc welding. A preceding paragraph dis-

(Continued on page 180)

*The Lincoln Electric Company, Cleveland, Ohio.

INDEX TO ADVERTISERS

A

Alliance Machine Company 205
Allis-Chalmers Mfg. Co. 194–210

B

Bartlett Hayward Company ..... Cover 1
Blaw-Knox Company 216
E. W. Bliss Company 182
Boxill-Bruel Carbon Co. 232
Bussmann Mfg. Company 226

C

Chicago-Jefferson Fuse & Electric Co. 222
Cleveland Crane & Engineering Co. 202
Clark Controller Company 233
Condit Electric Mfg. Corp. 234
Crocker-Wheeler Electric Mfg. Co. 221
Crouse-Hinds Company 231
Cutler-Hammer Mfg. Co. 229
Cutter Electric & Mfg. Co. ..... Cover 3

D

De Laval Steam Turbine Co. 209–215
Delta Star Electric Co. 206
M. H. Detrick Company 238
Doubleday-Hill Electric Co. 206
John C. Dolph Co. 217

E

Economy Fuse & Mfg. Company 196
Electric Controller & Mfg. Co. 189
Electric Power Equipment Corp. 228
Electric Service Supplies Co. 192
Electro Dynamic Co. 188

F

Farrel-Birmingham Co. 184–185
Freyn Engineering Company 190

G

Gears & Forgings, Inc. 223
General Electric Co. ..... Cover 4
Graybar Electric Company 212

H

Harnischfeger Corporation 219
Hyatt Roller Bearing Co. 204

I

International Combustion Engineering Corp. 183
Iron City Electric Co. 215
I. T. E. Circuit Breaker Co. ..... Cover 3

J

Johns-Manville Corp. 198

K

Keystone Lubricating Co. 237

M

Martindale Electric Co. 211
Moloney Electric Co. 205
Monitor Controller Co. 197
Morgan Construction Co. 213
Morgan Engineering Company 191
Morganite Brush Company 212

N

National Carbon Company 187
New Departure Manufacturing Co. 199
Nichols-Lintern Co. 195
Norma-Hoffmann Bearings Corp. 193
R. D. Nuttall Co. 201

O

Ohio Electric & Controller Co. 224

P

Pittsburgh Transformer Company 210

R

Reliance Electric & Engineering Co. 227
Rockbestos Products Corp. 200
Roller-Smith Company 208
Rowan Controller Company 214
Rumsey Electric Company 208

S

Shepard Electric Crane & Hoist Co. 230
Smith & Serrell 207
Stackpole Carbon Co. 236
Standard Underground Cable Co. 207
SKF Industries, Inc. 220

T

Thompson Electric Company 211
Timken Roller Bearing Co. 235
Tool Steel Gear & Pinion Co. 209
Trico Fuse Mfg. Company 218
Trumbull Electric Mfg. Co. 213

U

United States Graphite Company 210

V

V. V. Fittings Company 225

W

Westinghouse Elec. & Mfg. Co. 186–Cover 2
Weston Electrical Instrument Corp. 214
Edwin L. Wiegand Company 203

*Effect of Grounding on Telephone Interference**

By J. J. PILLIOD†

THE subject which your Association has assigned for this part of the program is "Effect of Grounding on Telephone Interference," and it is understood that the general program is to deal with three phase, three wire, power transmission systems in which the transformers are star connected with various conditions of grounded and ungrounded neutral.

In connection with the discussion of this subject, it may be helpful to first consider briefly that part of the telephone plant most frequently involved in exposures to power transmission lines and therefore subject to possibilities of inductive interference under certain conditions, and to review some of the services which that plant is designed to furnish. Then the situation where power circuits of the classes referred to and signal circuits of the various kinds are generally parallel will be discussed, with particular reference to the effect of grounding the neutral. Such situations may cause potentials to be imposed on the signal circuits from these power circuits, by induction, resulting in two general classes of interference.

1. Noise which interferes with and may interrupt telephone service, or induced currents of frequencies higher than the fundamental of the system, which may affect other signal circuits.
2. Effects from induced potentials at fundamental frequency, which may seriously affect or totally interrupt telephone or other signal service. These include acoustic shock and hazard to users of telephone service and to telephone employees, as well as the operation of protectors and breakdown of insulation of apparatus or wiring.

The first class may be expected under conditions of normal operation of a power system and will usually be greatly accentuated under abnormal conditions. The second class is usually found during periods of abnormal unbalance on these power lines, as when faults occur.

DESCRIPTION OF TELEPHONE PLANT AND SERVICE

Telephone service may be classified broadly as local exchange and toll or long distance service. While the local exchange plant must be taken into account in the consideration of the general interference problem, it seems desirable to limit the discussion in this paper to the plant involved in toll or long distance service.

In general, the outside lines used for the toll circuits are made up of open wire carried on pole lines, aerial or underground cable and combinations of these types of plant. Figure 1 is a map indicating the network of Bell System lines over which toll circuits are carried. This network has been constructed as required by the growth in the business, and is made up of trunk lines carrying long toll circuits and other lines carrying shorter toll circuits. Choice of routes in this network involves problems somewhat similar to those met in the construction of power lines. Long telephone lines, like high tension transmission lines, must reach certain points, between which there is some freedom as far as location is concerned. Shorter toll telephone lines, like primary distribution circuits, must radiate from these points into surrounding communities with comparatively less freedom of routes. This matter of routes is mentioned here because one of the most effective methods of avoiding inductive interference is by separation and it has been the endeavor to so locate telephone lines as to avoid, wherever practicable, situations of proximity with power transmission lines. By co-operation and advance planning, it should be possible to accomplish much along this line where reasonable freedom in selection of routes is possible. In those cases where, due to circumstances, the choice of routes is somewhat restricted and situations of proximity cannot be avoided, methods of mitigation which will give substantial relief may be used and, here again, co-operative study and action should give the best results.

Figure 2, which is a photograph taken just west of Pittsburgh, illustrates typical toll line construction where the aerial wire type of plant is used. Each pole line is built to carry a definite number of wires, which are placed on 10-pin crossarms. The wires are of suitable gauges to meet transmission and mechanical requirements and are so arranged that phantom circuits may be obtained, that is, three telephone circuits are made available from two pairs of wires. In addition, carrier current systems may be operated on some of the wires, making available additional circuits.

The other type of plant is cable and this is extensively used in those areas in which the circuit requirements are comparatively heavy. As would be expected, the use of cable is very large in subscribers' circuits. Cable is also used for many of the short toll circuits connecting large centers of population not widely separated. Within the last decade, the developments in the art and increased requirements of the public for telephone service have made it practicable to greatly extend the use of cables between large centers of population separated by several hundreds of miles, and where the circuit requirements would necessitate such a number of aerial wire lines that the use of toll cable construction is advantageous. Figure 3 illustrates a typical aerial toll cable line, and one of these cables may carry more than 250 telephone circuits and 500 telegraph circuits. The cables are placed underground or aerially, as may be most advantageous under all of the circumstances. Figure 4 shows the general routes of some existing and proposed long toll cables.

On these two general types of facilities, that is, open wire and cable, are carried the telephone conversations which take place between the communities of the nation. The problems involved in transmitting the tiny amount of energy which is developed

*Presented before Pittsburgh Section, A. I. & S. E. E., February 3rd, 1928.

†American Telephone & Telegraph Co., Long Lines Dept., New York, N. Y.

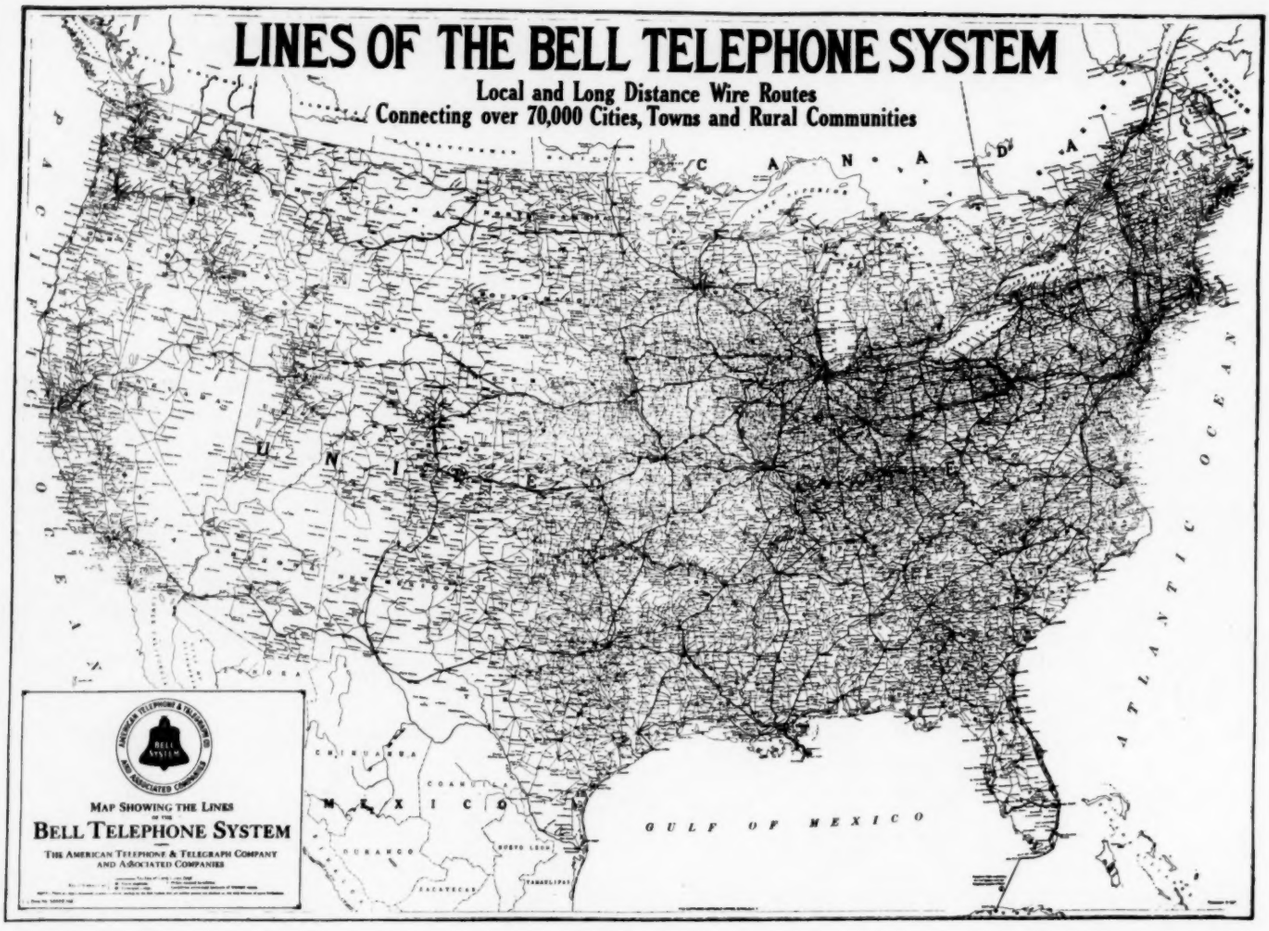

LINES OF THE BELL TELEPHONE SYSTEM
Local and Long Distance Wire Routes
Connecting over 70,000 Cities, Towns and Rural Communities
CANADA
U N I T E D
M E X I C O
GULF OF MEXICO
ATLANTIC OCEAN
MAP SHOWING THE LINES OF THE
BELL TELEPHONE SYSTEM
THE AMERICAN TELEPHONE & TELEGRAPH COMPANY AND ASSOCIATED COMPANIES

FIG. 1.

in the telephone transmitter over the varying lengths and types of circuits which may be required in different connections, and delivering sufficient energy to the receiver at the distant end to properly actuate that instrument, undistorted with respect to wave form and unimpaired by foreign potentials which may have been imposed upon the circuit somewhere throughout its length, are fully covered in literature which is available to all who are interested. It seems desirable to mention here, however, that on open wire circuits longer than about 150 miles and on cable circuits longer than about 50 miles, additional energy is introduced into the circuit at regular intervals by means of telephone repeaters or amplifiers. This is mentioned to emphasize the fact that induction in the range of telephone frequencies in one part of a long telephone circuit, may be carried through to the end of the circuit, with its same relation to speech energy as existed at the point where it originated. In telephone circuits, interference introduced at different points may be cumulative and this effect is of particular importance on long circuits.

Methods have been devised and have long been in operation whereby telegraph circuits are superimposed upon open wires provided for telephone circuits, and practically all wires on the pole lines of the type indicated in Figure 2 have assigned to them, at one time or another, telegraph circuits which do not detract from the general usefulness of the wire from the standpoint of telephone service. Similarly, in the long toll cable plant, telegraph circuits are superimposed upon cable circuits used for telephone service and, in addition, it has been found advantageous in some cases to utilize cable circuits solely for telegraph transmission.

There are two other important uses applied to the network of telephone circuits. One of these is the transmission of programs to radio broadcasting stations for chain broadcasting. The second, which may not be so generally known, is the transmission of pictures over wires, or telephotographs to Boston, New York, Atlanta, Cleveland, St. Louis, Los Angeles and San Francisco, and the network of circuits used to connect these points is one which demands reasonably constant transmission conditions, in order that the received pictures may be free from imperfection.

To indicate the extent of the service that may be involved in a section of line such as that shown in Figure 2, there are listed in the following table, the telephone circuits used for public message traffic and carried on that particular pole line, which is just one of the routes from Pittsburgh to St. Louis.

Number on this line	Circuit Group	Circuit Miles
3	Pittsburgh-St. Louis	1,923
1	Pittsburgh-Indianapolis	386
1	Pittsburgh-Louisville	444
7	Pittsburgh-Cincinnati	2,529
1	Pittsburgh-Dayton	290

1	New York-Kansas City	1,301
3	New York-St. Louis	3,063
2	New York-Louisville	1,644
3	New York-Indianapolis	2,279
1	New York-Dayton	677
1	Cincinnati-Washington	632
2	Cincinnati-New York	1,451
1	Philadelphia-St. Louis	936
2	Pittsburgh-Cambridge	258
1	Pittsburgh-Marietta	160
2	Pittsburgh-Charleston (W. Va.)	594
1	Pittsburgh-Huntington	346
2	Pittsburgh-Washington (Pa.)	94
	Total	19,007

The number of messages completed per day over each of the circuits listed above will average about 26.5. A part of these messages terminate at the points shown in the table for each circuit group, and a part are switched to points beyond. Taking

FIG. 2

account of switched connections, the total number of message miles per day handled over the circuits listed is in the order of 650,000.

In addition to the telephone message circuits, this section of pole line also carries one telephone circuit furnished under special contract between Pittsburgh and Wheeling, 74 miles, and one circuit between Pittsburgh and Cincinnati, 343 miles, which is an essential link in the Blue network furnished the National Broadcasting Company for the transmission of program material to radio broadcasting stations. Service is furnished daily over this latter circuit to Cincinnati, Chicago, St. Louis and Detroit and frequently this service is extended to supply a number of other broadcasting stations as far south as Jacksonville, Fla., north to Minneapolis, Minn., west to Omaha and Kansas City, and southwest to San Antonio, Tex.

Forty-five telegraph circuits, totaling 66,041 miles, are also operated over this line and used to furnish telegraph service to customers under special contract. The line also carries four telegraph wires, used for company purposes, with a total mileage of 8,796. The telegraph circuit mileage affected by a total interruption in the section of line shown in Figure 2 would be 74,837.

While the facilities provided by a particular line may vary considerably, all of the services are of great importance and should be furnished with as few imperfections as possible. Therefore, in the

FIG. 3.

design of the facilities which are used to provide these services, there has been given thorough consideration to those things that will tend to minimize, as far as practicable, liability to interruption or impairment from all causes, including induction from power circuits.

NOISE IN TELEPHONE CIRCUITS FROM INDUCTION

In the transmission of signals over a communication line, the power used, and thus the voltage and current, vary from instant to instant. In telephone

FIG. 4.

circuits this variation is extremely complex, and the current which reproduces the voice in a distant telephone consists of a number of component alternating currents comprising a band of frequencies which may be as much as several thousand cycles in width. For the transmission of power, an alternating current line transmits currents and voltages which also vary from instant to instant and which are accom-

panied by their respective fields of influence, one by a varying condition of flux and the other by a varying condition of stress. If a telephone circuit lies within either of these fields of influence, there will be a transfer of energy to it and if, as a result of this transfer of energy, currents flow in the telephone circuit of a character to cause a response in the receiver, noise will result.

This transfer of energy usually results in two distinct effects; one, induced potentials between wires of the telephone circuit within the exposed section, which may cause what has been termed "metallic circuit noise," and the other, induced potentials between the wires of the telephone line and ground, which results in what may be termed "noise to ground." Induced potentials, although instantaneously of the same polarity and magnitude between the wires and ground, may be productive of circulating currents in the metallic telephone circuits causing noise, as a result of minute variations in series impedances of the two sides of the telephone circuit or in their admittances to ground or to other wires.

By study and co-operation, it is frequently possible to bring about an adjustment in the relations between the wires of the telephone line and the power line by co-ordinated transpositions in the power line, in the telephone line, or in both lines, whereby the transfer of energy in one short section of the exposure so counteracts the transfer of energy in an adjacent short section as to materially neutralize the effects. The degree of success with which this can be done is dependent to a large extent upon the nature of the exposures, and the characteristics of the particular power system which include transformer connections and arrangements of any grounds.

HARMONICS IN POWER CIRCUITS

Telephone circuits are necessarily designed to transmit frequencies from about 100 cycles per second upward. This range of frequencies is higher than the fundamental frequencies usually employed for power transmission, and thus the noise in telephone circuits caused by potentials induced in them from power circuits is due very largely to harmonics of the fundamental power frequency. The harmonics in a power circuit may cover a very considerable portion of the speech range and there is a fairly definite relation between the frequencies of the induced currents and their detrimental effects, as indicated on the curve in Figure 5. The disturbing effect from the standpoint of noise of the currents and voltages in a given power circuit of the kind under discussion and under normal operating conditions is determined largely by the presence of some or all of the frequencies indicated on that curve. The frequencies present, together with their relative magnitudes, determine what has been called the * "telephone interference factor" of the currents or voltages concerned. The harmonics that usually occur are the odd multiples of the fundamental frequency, and these have been observed over a considerable portion of the frequency range used on signal circuits. A discussion of wave form, which of course is determined by the harmonics present, will not be undertaken in this paper, but it may be mentioned that the nearer power circuits approach the condition where only fundamental frequencies are present, the easier becomes the problem of noise in telephone circuits, other factors being equal.

In considering the problem under discussion, it is important to note that it has been found desirable and convenient to divide both the voltages and currents of a power circuit into two sets of components, namely, "balanced" and "residual." The balanced currents and voltages are those components whose respective vector sums, in the several conductors of a power circuit, are zero at every instant. The residual current as here used is the vector sum of the total currents in the several conductors of a power circuit at any instant, while the residual voltage is likewise the vector sum of the total voltages to ground of those conductors.

The balanced components are in effect confined to the line conductors, while the residual components

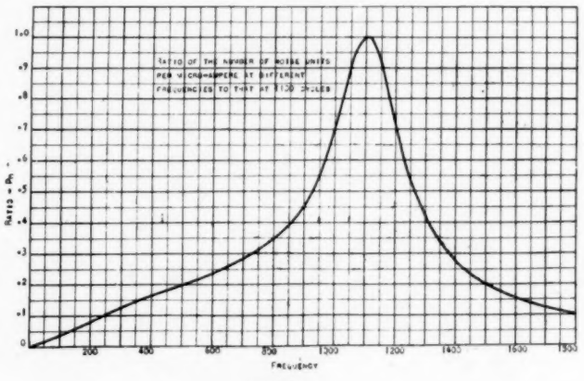


FIG. 5.

act in a manner similar to single phase currents or voltages in a circuit consisting of the three line conductors in parallel as one side, with earth return as the other side. For this reason, transpositions in a power circuit cannot reduce the inductive effects of residuals except in so far as they reduce the residuals themselves. Residuals usually cause much larger inductive effects than balanced currents or voltages of equal magnitude.

The third harmonic and its odd multiples, which are impressed upon a power system by star grounded transformers, are in phase in all three line conductors of the transmission line and therefore appear as voltages or currents between line and ground and not between line conductors. Any currents that flow at these frequencies have a ground return and their effect is that of residuals.

The other harmonics appear as voltages between wires and consequently produce currents in the different phase wires of the transmission line. On account of unbalances or inequalities among the admittances to ground of the several conductors of the power circuit, these voltages may also cause residuals. If the power system is isolated from ground, residual voltages will result, while with a star grounded system a residual current will exist, but the residual voltage at these frequencies will be considerably reduced.

From the preceding, it is clear that it is very desirable from the standpoint of induced potentials in telephone circuits causing noise, to keep the ad-

*Review of Work of Sub-Committee on Wave Shape Standards of the Standards Committee. Harold S. Osborne, Transactions A. I. E. E. 1919, page 261.

mittances to ground of the several wires of the power line equal, in order that the residuals due to this cause may be of small values, while for the effects of the third harmonic and its odd multiples, in so far as they cause induced potentials to ground in telephone circuits, there are two possible remedies—one, suppress them, and the other, keep the lines so separated that the field of harmful influence of the power line will not extend to the telephone lines.

CO-ORDINATED REMEDIAL MEASURES TO REDUCE NOISE

The most effective method of reducing inductive disturbances is by separation of the lines, but in situations where sufficient separation cannot be obtained to give freedom from interference, it is frequently possible to materially reduce the severity of the effects by the application of other co-ordinated remedial measures to the power system, to the telephone system, or to both.

Two benefits may be derived from a proper arrangement of transpositions in the power transmission line from an inductive co-ordination standpoint.

a. The reduction in magnitude of residual components.
b. The mitigation of the inductive effects of balanced components.

To accomplish the former, the entire line must be in a proper condition of balance from the standpoint of admittances to ground and hence transpositions throughout the entire length of the power line are effective for residuals caused by differences in the capacity of line wires.

To accomplish the latter, the desired effect must be brought about within the exposed section and hence there must be, within the exposure, co-ordination between the transposition arrangement of the power line and the transposition arrangement of the communication line.

To adequately cover the matter of co-ordinated transposition designs in the telephone and power lines would require a lengthy discussion, and it seems best to limit this phase of the subject here to a few brief statements. The transposition designs employed in the telephone lines can be adapted to meet, with reasonable accuracy, the varying conditions of power exposures and in addition are designed to permit of power transpositions, at reasonable intervals, whereby both the reduction of residuals and the mitigation of the effects of balanced components can be brought about. In general, transpositions on the power line at approximately one mile intervals or three mile barrels within the exposure can be co-ordinated reasonably well with telephone transposition designs, although each particular exposure requires study.

Outside the exposure, there is some limitation to the distance between transpositions in power lines to effectively reduce residual components, and with due regard for the effects of different configurations and dimensions in the power line, it has been recommended that in a single circuit, three phase line with triangular configuration, the length of power barrel be not more than 12 miles and that for all other configurations the length be not more than 6 miles. the entire matter of co-ordinated transposition designs is one that can be handled best by a co-operative study of each case whereby all of the special features of the situation can be taken into account. With such co-operative action, much can be accomplished for the mitigation of noise in those cases where increased separation alone is not a practicable engineering solution.

Analogous to the transposition designs in open wire lines, the conductors of the long toll cable are so arranged with respect to each other that within the cable itself a close degree of balance is obtained, not only with respect to one conductor to another, but with respect to a paralleling line. Thus, there is built into the cable a high degree of balance between the cable circuits and circuits on paralleling transmission lines. Were it not necessary to consider the effects of residuals in the power circuits, the problem of inductive interference in cable circuits would be greatly simplified.

While the matter of wave form is determined largely by the design of power apparatus, it is found occasionally that some particular generator, motor, electric furnace, or other equipment is responsible for the production of harmonics which maks the transmission line productive of an excessive amount of noise in paralleling telephone circuits and circumstances might be such that changes in, or the replacement of the particular apparatus might constitute an effective remedial measure.

Effect of Transformer Connections During Normal Conditions

Under normal conditions of the power circuit, the effect of the several types of transformer connections on noise producing characteristics of a power line can be summarized as follows: In the isolated system, with either delta or star connected transformers, the third harmonic and its odd multiples are not impressed on the transmission line as residuals. Both of these systems may be unbalanced with respect to ground, as a result of inequalities between the admittances to ground of their several conductors, but a close degree of balance can be effected by proper transpositions in either case.

When the neutral of an ordinary star connected transformer bank is grounded, the third harmonic and its odd multiples are impressed upon the transmission line and appear as voltages between line wires and ground. As previously indicated, these voltages and residual currents which flow through the admittances to ground of the line conductors may have very large inductive effects. In the case of a two winding transformer bank having one side star connected, the third harmonic and its odd multiples can be greatly reduced by connecting the other side in closed delta. Where the transformer bank is star-star connected, a reduction can be effected by the use of a properly designed third or tertiary winding on each transformer, these windings being connected in closed delta.

The presence of more than one grounded neutral on the system may increase the noise producing possibilities of a transmission line because of the fact that the third harmonic and its odd multiples are afforded a circuit consisting of the transmission line wires as one side and ground as the other, under which condition the magnitudes of the currents that flow in this path may be no longer largely dependent upon the capacities between the transmission line

wires and ground. Even with a set of closed delta windings on the transformers, the third harmonic and its odd multiples are not entirely eliminated and the effect of such as remain may be increased by the presence of more than one grounded neutral on the system.

In making a comparison between grounded and ungrounded systems, it will be assumed that proper steps for the reduction of the inductive effects have been taken. This means that the power circuit is well balanced, that transpositions are installed in the transmission line and are properly co-ordinated with transpositions in the signal line, and, in the case of the grounded system, that the third harmonic and its odd multiples have been adequately reduced. If, under these conditions, there is but one ground on the system and the transformers are properly designed and are not operated above their rated voltages, it can be said that the differences, from a noise standpoint, are probably small during times or normal operation.

Induction at Fundamental Frequency

General

Induced potentials at fundamental frequency which may seriously affect signal circuits are usually found during periods of abnormal unbalance on power lines, as when faults occur.

Faults on a three phase system may be divided into three general classes:

a. Three phase short circuits, involving all three of the line conductors at a given point.

b. Single phase short circuits, in which two of the line conductors are short-circuited at a particular point.

c. Ground faults, that is, faults between the line conductors and ground.

In cases where the faults are three phase or single phase in nature, involving no accidental contacts with the ground, the fault currents are confined to the line wires. Consequently, for a given amount of fault current and given exposure conditions the magnetically induced voltages, at low frequency, with these two classes of fault will be much less than they will be in the cast of a ground fault, in which latter instance the paths of the "going" and "return" fault current are, in effect, widely separated. For this reason, the following paragraps are confined to a discussion of faults involving accidental contacts of the power conductors with the ground.

A ground fault on a phase wire of a grounded neutral system will produce a short circuit of relatively low impedence and the magnitude of the short circuit current will depend upon the total impedance of the grounded loop thus established. On the other hand, a ground fault on one phase wire of an isolated three phase system will not complete a metallic path to ground and hence will not of itself constitute a short circuit. However, under the condition just mentioned, the oscillations set up by the arc associated with the ground fault, or if the insulation is inadequate, the voltage rise on the two sound phase wires may cause a breakdown on one of these phase wires thus producing a short circuit, by way of the ground. The resulting short circuit, or at least a part thereof, will exist as a residual (or ground return) current.

The magnitude of the short circuit current is, of course, controlled largely by the short circuit capacity of the system. The larger and more extensive an isolated system, the more likely are such faults to occur. This is particularly true for systems of the higher voltages. Even without the second breakdown, there is a reactive path to ground through the electrostatic capacity to ground of the system conductors, and the presence of this reactive path permits unbalanced

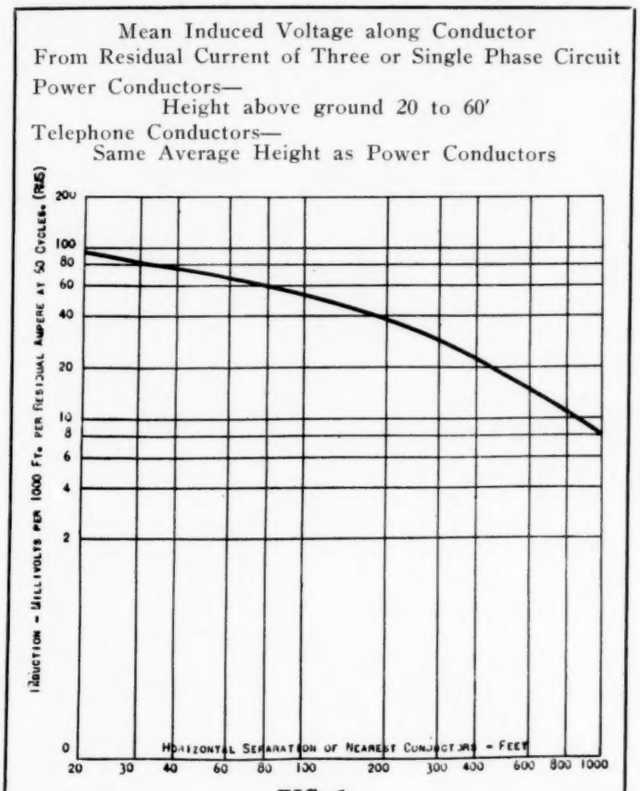


FIG. 6.

charging currents to flow as a result of a single ground fault. The larger the power system network and the higher the power line voltage, the larger this unbalanced charging current will be. It follows, therefore, that the smaller the extent of the power system, the smaller will be the unbalanced charging current and also the likelihood of occurrence of a second breakdown. In the case of an extensive power system isolated from ground and operating at the higher voltages, the effects from residual current may be as severe as in the case of lower voltage systems with solidly grounded neutral.

Computation of Magnetic Coupling of Power and Communication Circuits at Low Frequencies

The method which is employed at present for computing magnetic induction between grounded power circuits and signal circuits makes use of an "equivalent ground plane."* It has been found from the results of tests that the depth of that "equivalent plane" varies in different sections of the country. In the absence of specific test data regarding the depth of the equivalent ground plane in a particular geographic area, the curve of coefficients of

*See pages 654 and 655 of the publication on "Inductive Interference," issued by the Railroad Commission of the State of California on April 1, 1919.

induction shown in Figure 6, which is based on field tests in a number of locations, has been found useful in estimating the inductive coupling with respect to ground return currents at 60 cycles. By the application of this curve, it will be clear that very high and dangerous voltages can be induced in signal circuits under conditions that might occur unless guarded against, and a simple example has been shown in Figure 7 to illustrate this.

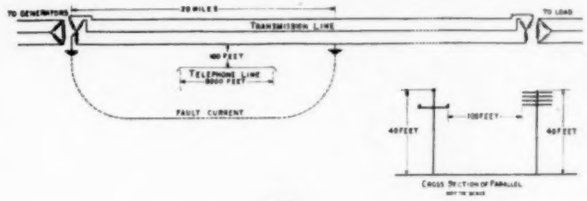


FIG. 7.

ASSUMPTIONS

Transmission Line

66KV—Three Phase—60 Cycle—Delta-Star Connected —Neutral Ground at Generating Station End

Telephone Line

Same average Height as Power Line

Condition of Exposure

Uniform Parallel — 9000 Feet in Length — 100 feet Separation

Condition of Fault

Ground on Single Wire of Transmission Line, Beyond Exposure From Generating Station—Fault Current 1000 Amperes—Equivalent Ground Plane 500 Feet Below Power Line.

COMPUTATIONS

From Figue 6, Millivolts Per 1000 feet of Parallel Per Residual Ampere = 53 = .053 Volts

Voltage to Ground on Telephone Wires for Conditions Assumed, 9x1000.053 = 477 volts (RMS)

(Not to scale)

The magnitude of fault current is, of course, one of the important factors which determine the amount of induced voltage. The engineers familiar with the details of the design of the power system usually have the information from which fault currents can be estimated. Such estimates furnished by them are very helpful in the co-operative studies of any particular case.

It will be noted that the curve just referred to covers separations lying in the range of 20 to 1,000 feet. Until recently, it has been practicable to confine the consideration of low frequency inductive effects from power systems, in large part, to exposures having separations of less than approximately 1,000 feet. With the present tendency towards large interconnected power networks and higher operating voltages and with the larger amounts of power for which the supply systems are designed, it has become necessary to consider low frequency inductive effects from long exposures at separations of more than 1,000 feet. Studies for the purpose of determining the relative magnitudes of the coefficients of magnetic induction in the range of separations from something less than 1,000 feet upward are under way, but have not yet been completed. Theoretical work bearing on this problem has been carried out both in this country and abroad. A method which seems to have promise in this connection has been developed by Dr. J. R. Carson and was published in the October, 1926, issue of the Bell System Technical Journal.* Plans are being made for carrying out experimental work which is expected to provide information regarding the coefficients of magnetic induction at the wider separations.

Co-ordinated Remedial Measures to Reduce Induction At Fundamental Frequency

As in the case of the inductive problems presented by normal operating conditions, co-ordinated methods for the purpose of minimizing the low frequency inductive effects experienced at times of fault on a power circuit may be diveded into three groups, as follows:

1. Methods applicable to the power system.
2. Methods which will reduce the inductive coupling of the power and communication circuits.
3. Method applicable to the communication circuits.

The more important of these measures are:

(a) Separation of the two classes of line.

(b) Limitation of fault current.

(c) Reduction of frequency of occurrence and duration of abnormal condition.

(d) Shielding.

(e) Devices on communication circuits.

A more detailed discussion of these items is given below.

(a) Separation of the Two Classes of Line

It is evident that increasing the separation of the two classes of line will decrease the inductive coupling in a given length. Therefore, it is desirable that the lines be kept as far apart as practicable, at least until such time as other methods of accomplishing the desired result may become available.

Of course, in many cases service reasons and physical or topographical conditions, as well as economic considerations, make it impracticable to avoid interference at low frequencies by measure involving increased separation only. However, by co-operative advance planning of routes, it is often possible to avoid the creation of new exposures and, when lines are being rebuilt, to eliminate, or reduce the severity of, an appreciable number of existing exposures by rerouting one or the other of the lines. It is recognized that, in the past, a large number of exposures have been created which, in the present state of the power and communication arts, or as a result of changed conditions in the specific situations, involve possibilities of severe low frequency inductive effects. A number of these situations have been taken up with the power companies and joint studies are being made with a view to determining the most practicable solutions.

(b) Limitation of Fault Current

The limitation of fault current strikes in effect at the source of the induced voltages and is a method which is productive of direct benefits. Therefore, it should receive serious consideration in any particular case and be used if necessary to provide the best solution. Among methods which have been considered for this purpose are resistance or reactance in the neutral ground connection and current limiting reactances in the line. A discussion of the advan-

*"Wave Propagation in Overhead Wires with Ground Return," pages 539 to 554.

tages and disadvantages of such devices, from the standpoint of the power engineer, does not come within the scope of this paper, but some of the factors of this nature which may require consideration when current limiting devices are inserted in the neutral are:

a. The advantage from the standpoint of power system operation of limiting fault current.
b. The design of adequate relay systems under conditions of limited fault current.
c. The rise in potential, above ground, of the neutral of the transformers at times of ground fault.
d. Other considerations, such as the space required for the current limiting apparatus, the maintenance of that equipment, etc.

Broadly speaking, it may be noted that a number of power systems are now operating with resistance in the neutral and while there may be some variation in opinion as to the relative amount of resistance which it is practical to employ, it would seem that in certain cases, with modern relay systems, it should be practicable to limit the short circuit currents sufficiently to meet the inductive requirements fully and to obtain adequate relay protection of the power system at the same time. In other cases, current limitation may be only a partial remedy, and it would be necessary to supplement it by other co-ordinated methods. It is also recognized that in some cases methods other than current limitation devices would be more satisfactory.

In certain instances, it may be practicable to reduce the short circuit currents (and also the cost of current limiting devices) by reducing or relocating the number of points at which the neutral is grounded.

As other items, which do not necessarily limit the magnitude of the fault currents but which do limit the frequency with which faults will occur, may be mentioned the desirability of so designing transmission, lines and associated apparatus that they are of adequate mechanical strength and that the insulation has a liberal factor of safety between its flash-over voltage and the voltage which it must normally withstand. In this connection the desirability of making every reasonable effort to replace defective insulators before they result in faults is also apparent. The items mentioned in this paragraph are beneficial alike from the standpoint of power service and inductive co-ordination.

(c) Reduction of Duration of Abnormal Conditions

All other conditions being the same, the amount of energy transferred into the communication circuit and the effects of the induced voltages depend to a considerable degree upon the duration of a fault upon the power circuits. Thus, anything which can be done to shorten this interval will be of assistance in connection with the low frequency induction problem. Two types of power system apparatus which immediately come to mind in this connection are the relays and switches.

There are two properties of relays which are directly related to low frequency inductive effects, namely: (1) the ability to detect and respond to detrimental disturbances on the power system and (2) the time required to clear disturbances. There are many disturbances on power lines that affect communication circuits but that do not necessarily operate the relays. Some of these are disturbances such as are created by power system switching, self-restoring faults to ground, etc. If only overload or reverse power relays are installed in the phase wires, the relays must be set at currents appreciably greater than the normal load currents. Under this condition, the current required to operate the relays, especially if it is residual, may be of sufficient magnitude to induce very large voltages on exposed communication circuits. The employment of relays which operate on residual currents offers a possible means of avoiding this difficulty. In this latter connection, the sensitivity of existing types of relays must be considered. However, the use of ground relays of the more sensitive types which are now available would seem to have advantages not only from the standpoint of inductive co-ordination, but also with regard to power system protection.

Of course, the time required to clear a disturbance is dependent not only upon the relay speed but also upon the speed of the switch controlled by the relay, that is, this interval is dependent upon the overall speed of a given relay switch combination. The possibility of developing high speed circuit breakers has received attention from time to time and it is understood that the manufacturers are devoting considerable study to that problem.

In connection with the preceding paragraphs, it is appreciated that the extent to which it will be practicable to shorten the interval before disconnection in any given situation will depend not only upon the time necessary to open the switches but also upon the time-graded relay scheme which may be required to insure satisfactory operation of the power system.

(d) Shielding

Grounded shield wires on telephone lines are grounded cable sheaths have been considered. The purpose is to introduce counter e.m.f. in the telephone wires and while this method does not constitute a practical solution of the general problem, it may be helpful and may offer a solution in some cases.

Overhead ground wires on the transmission line operate to mitigate the low frequency induction effect by reducing the magnitude of the fault current flowing in the earth, or looking at the matter from another point of view, by the introduction of counter e.m.f. in the telephone wires. As in the case of grounded shield wires on the telephone line, this does not seem to offer a general solution, but may, either alone or in combination with other measures, afford sufficient reduction of induced potentials to ground in a particular situation.

(e) Devices on Communication Circuits

In the present state of the art, the measures which can be applied generally to the communication circuits, for the purpose of reducing the effects of high voltages which are induced at times of abnormal conditions of a supply circuit, are limited.

Electrical protection is provided in the plant of the Bell System to assure the greatest practicable degree of freedom from personal injury to patrons and employees, fire hazard, property and apparatus damage. The protective apparatus employed in-

volves various arrangements of three basic elements, namely:

1. Open-space cut-outs.
2. Fuses.
3. Heat Coils.

The arrangement and types of these elements which are used at any given point on a communication circuit depend, of course, upon the part of the telephone plant that is to be protected at that location. A general description of the nature and function of the three elements just mentioned follows:

The open-space cut-out provides a path to ground for voltages impressed on the communication conductor and is made up of two blocks so arranged as to have a small air gap between them. One of the blocks is of carbon while the other is of porcelain, provided with a carbon insert which is fastened by means of a cement that melts at a relatively low temperature. When the block becomes sufficiently heated by a discharge maintaining a continuous arc across the air gap, the cement becomes soft and allows the carbon insert to be pushed against the other block of the pair, thus solidly grounding the communication conductor. As a result of this grounding, a current will exist in the communication conductor and it is the function of the fuse, previously mentioned, to interrupt currents which if continued would create a fire hazard by overheating the conductors or protector mountings. The heat coil operates on comparatively small currents and its purpose is to provide a means of grounding the telephone conductor in case currents of magnitudes sufficient, if continued, to overheat terminal apparatus and thereby produce a fire hazard are impressed on the telephone conductor by voltages insufficient to operate the open-space cut-out.

The protective apparatus just mentioned constitutes only a second line of defence against the effects of high induced voltages.

For certain types of circuits, the induced voltages to ground or along the conductors might also be reduced by drainage, by which is meant the provision of paths from the conductors to ground in which currents are established by the induced voltages. Some of the railroads and power companies have used this method on their special telephone lines which are exposed to high voltage induction. However, in general, drainage could not be applied to long distance telephone systems without greatly hampering their operations, since it would prevent the use of direct or low frequency currents for telegraph or signaling, or for the location of faults, would introduce losses of energy and irregularities of impedance which would limit the usefulness of the toll circuits, and would interfere in other ways with their operation.

The installation on the communication lines at the ends of the inductive exposure of special isolating transformers with high dielectric strength has also been considered. Such transformers, however, also have the interfering effects with long distance telephone circuit operation mentioned above in discussing drainage coils, and furthermore, do not afford protection to employees working on the communication circuits, since they merely confine the induced voltages to the exposure and do not remove these voltages from the telephone lines.

Various special devices for application to the communication circuits other than those discussed in the preceding paragraphs have been considered for reducing the effects of low frequency induced voltages. Although some of these have given a limited degree of relief and have served in some cases as temporary measures, none of these devices has as yet been found which is sufficiently reliable to warrant its general use.

Summary

Where signal circuits and power transmission circuits are in proximity and the electrical effects of the latter extend far beyond the neighborhood of the power conductors, voltages and currents may be induced in the signal circuits of sufficient magnitude and of such characteristics as to interrupt or seriously interfere with service and to cause conditions hazardous to employees and the public. Separation of the routes and other measures available, which will limit the influence of the power circuits on other lines and thus reduce or eliminate these effects, should be applied as may be necessary to give a satisfactory solution in any particular case.

It seems clear that a full appreciation and understanding of the problems involved in both systems would be very helpful in connection with co-operative work of this kind. The other papers on this program which discuss the various power system problems involved in grounded neutral systems will assist those who are in the telephone business, and it is hoped that the foregoing may be helpful to power people, who may have occasion to consider the problem of inductive co-ordination.

In any such situation requiring consideration, co-operative advance planning should be of great assistance and should result in the final adoption of the most economical and mutually satisfactory plans. This, in the long run, is in the direct interest of both the power and communication systems.

*Theory of Grounding**

By F. C. HANKER†

INTRODUCTION

DURING recent years the Central Station Industry has taken rapid strides in the progress of its development. Ever increasing kilowatt capacities are being installed in single generating stations with a like increase in connected loads at the substations. To accomplish these results in a satisfactory manner, both electrically and economically, it has been necessary to leave the field of low voltage, small capacity generating equipment and transmission lines and to adopt voltages of greater magnitude for the generation, transmission and dis-

*Presented before Pittsburgh Section, A. I. & S. E. E., February 3rd, 1928.

†Westinghouse Electric and Manufacturing Company.

tribution of central station power. With the tend ency toward increasing concentrated capacities and the consequent higher voltages necessary for generation and transmission, there has arisen a number of problems which for many years had not troubled the Central Station Industry.

With the industries requiring large blocks of central station power for their operation, the central station engineers have been confronted with problems of continuity of service, stability of system operation and effective systems of selective relaying as a means of maintaining service.

The problems of the electrical engineer in the Steel Industry are similar to those of other electrical supply systems differing only in degree. Their power supply is very largely generated in their own plants at the present time due to the availability of low cost fuels and waste heat from manufacturing processes. The conditions make it difficult for Central Station companies to compete on an economical basis and until such time as a mutually satisfactory arrangement can be made, it is probable that individual or group generating installations will continue.

Probably the problem most often presented for solution is the matter of grounding transmission and distribution systems. There are several factors of great importance involved in the problem of when, where and how to ground the system electrically. It is the purpose to outline in a brief way the more important factors which must be considered, and in addition, to summarize the experience of the Central Station industry as far as possible. In the discussion of Grounding we have been guided largely by the experience of the Central Station industry as it is practically the only source of information on grounding.

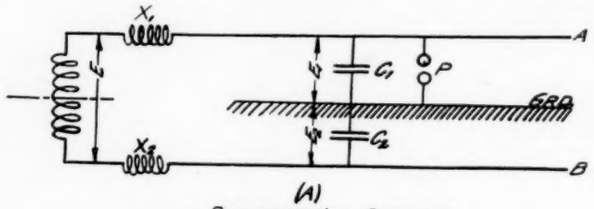
The practice of power supply systems in operating with the neutral isolated or grounded was under discussion for many years. In the early days there were two opposing groups; one strongly advocating grounding, the other as strongly opposing the practice. In recent years the opinions have largely crystallized in favor of stabilizing the neutral although there is still considerable difference of opinion as to the best methods of grounding, whether solidly or through some limiting means.

It is quite possible that a great deal of the controversial discussion was due to conflicting operating experience and possibly to a lack of appreciation of the conditions imposed on a system by the different methods of operation. There have been several theories advanced in the explanation of arcing grounds but there has been no general agreement as to the magnitude of voltages and surges produced. Each of the theories advanced depend upon different properties in the arc and until there is a more complete understanding of the fundamentals we can expect some difference of opinion.

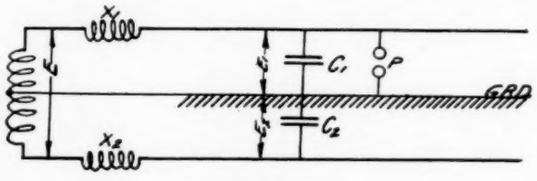
The operating engineer is confronted with the immediate necessity of maintaining service and naturally his records are maintained in such a way as to give a measure of the service that he is supplying for a given purpose. Inasmuch as the industry requires a continuous supply of energy, these records have usually been on the basis of service continuity either of a system as a whole, or of particular circuits. Unfortunately this does not give a complete picture of the situation as it does not take into account such intangible factors as deterioration of insulation that effects the life of the equipment. It is generally recognized that insulating material will withstand dielectric stress below a certain definite value for an unlimited period. It will also stand dielectric stresses exceeding this value for limited periods. It will, however, fail in case it is subjected to repeated over-potentials between a safe value and a value that would cause an immediate failure after some interval of time. It is this intangible factor that is not taken into account in operating records that renders it difficult to evaluate the advantages of neutral grounding.

THEORY OF GROUNDING

The conditions that exist in an ungrounded system can be explained more easily by using a simple equivalent circuit that for convenience we have shown as single phase. (Fig. 1-A). The circuit we have chosen to explain, the theory of "arcing grounds" would include a single phase generator with its midpoint isolated, and a circuit consisting



(A)
Representative Circuit of Isolated Neutral System.



(B)
Representative Circuit of Grounded Neutral System.

Fig. I

of two conductors having distributed inductance and capacitance. The capacity of the two conductors against ground can be represented by two condensers, C-1 and C-2, and the voltages from each line to ground by E-1 and E-2. These in general would be equal for a symmetrical system as the relative position would be maintained by the capacitance of the circuits and windings to ground. If, with a simple circuit as described, the ground is brought near one of the lines to within striking distance of the potential represented by the voltage "E-1", a discharge will occur over the conductor forming an arc, and the circuit of the impressed voltage "E" now comprises a condenser, C-2, in series with the multiple circuit of the condenser C-1 and the arc "P". The condenser C-1 rapidly discharges with the result that the voltage E-1 is decreased and the voltage E-2 increases. The charge on the condenser C-2 will increase as a result of the higher voltage and owing to the reactance in the circuit the charge will be oscillatory and cause

conductor "B" to raise to a value greater than the voltage of the circuit above ground. At the same time as the voltage E-1 decreases the discharge current through the arc decreases and therefore the voltage drop across the arc increases since it is a well known characteristic of the arc that the potential will increase when the current is decreased. When E-1 is equal to the voltage drop across the arc, the arc will be suddenly extinguished, the potential E-1 increases and owing to the reactance in the circuit the charge will be oscillatory, building up E-1 above its normal value. When this voltage E-1 reaches the necessary value it will break down the gap at "P" and re-establish. This will result in another train of oscillations. The arc is broken and re-established so quickly that the trains of oscillation overlap and excessive voltages may result.

Operating experience has demonstrated the correctness of this theory on systems of magnitude where the charging current is of sufficient value to maintain "arcing grounds" under adverse conditions. It is the usual experience that failures occur at widely different parts of the system, frequently resulting in short circuits that interrupt the service, and in failures of apparatus seriously affecting the system supply. This is the condition that existed at about the time systems had grown to a point that resulted in voltage surges of sufficient magnitude to cause an excessive number of apparatus failures. In the smaller systems it had been recognized that the condition existed but the relatively few apparatus failures had made it seem more desirable to attempt to maintain service even though the insulation was stressed higher than was considered safe. At that time it became a rather general opinion that the ultimate size of a system that could be conductively connected was limited to a very definite area.

The condition where the neutral of the system is grounded can be represented by a circuit similar to the other condition except that the midpoint of the generator would be connected to the ground. (Fig. 1-B). With this type of circuit the conditions are quite different and you do not have the possibility of recurring oscillations developing dangerously high voltages and maintaining them for sufficient time to cause apparatus failure. With this type of system if a ground "P" is brought near the conductor, a current flows across the gap which is fixed by the resistance and reactance of the generators and lines and does not depend upon the electrostatic capacity as in the ungrounded system. The potentials E-1 and E-2 of the separate conductors to ground will change depending on the impedance drop in the circuit and cause a small oscillation. After this occurs the resultant voltages E-1 and E-2 will remain fixed and a stable condition for the arc is established. This condition will maintain the arc at fundamental frequency.

The essential features of the ungrounded and grounded neutral systems can be shown by simple electric circuits that give the equivalent conditions described in the foregoing diagrams.

Engineers have been handicapped in a study of the conditions existing on circuits by the lack of adequate instruments which would have enabled them to study the fundamental conditions that exist. For many years there was very little definite knowledge as to the actual values of voltage surges existing on practical operating systems. There was considerable accumulated experience gained from failures of apparatus but unfortunately these values were not always sufficiently definite to be free from controversial discussions.

The expansion of the industry made it increasingly important that the fundamentals of voltage surges be understood so that proper protective means and remedial measures could be applied to prevent dangerous voltages that represented a hazard to satisfactory operation. In some of the earlier investigations gaps of various types connected with circuits of different constants were used in an effort to establish the wave form and magnitude of voltage disturbances. One rather comprehensive investigation on a cable system gave some indication of the voltage conditions that had been experienced in actual operation. Unfortunately the results were not sufficiently complete to confirm the theories as fully as would be desired. In carrying on laboratory experiments to develop recording devices, the principles underlying the Lichtenburg figure were carefully studied and resulted in the development of the klydonograph. Since the development of this equipment, data have been obtained on numerous systems throughout the country that have established very definitely the values of surge voltages that may be expected on the usual type of system. In general this data indicates that on the grounded system the maximum voltages that may be caused by system faults, switching, or other change in circuit conditions may reach a value equivalent to 2½ times the normal voltage. They further demonstrated that oscillations on systems of this type have been highly damped and as a result the possible damage is greatly minimized. On the other hand investigations that have been made on ungrounded systems have shown values as high as 4½ to 5 times the normal voltage and of a highly oscillatory character. It has been found that these surges are transmitted considerable distances, increasing in magnitude at points of discontinuity and reflection.

The results of klydonograph investigations with records of a great many surges resulting from various causes on transmission lines have given a more definite basis on which to judge the relative merits of the grounded and the isolated neutral system.

a. The quantitive measurements with the klydonograph agree with the theories regarding induced voltages and the protection against these afforded by the grounded neutral.

b. Flashovers and short circuits produce no serious voltage surges when the system neutral is grounded.

GENERAL CONSIDERATIONS OF GROUNDING

There is still some difference of opinion as to the best practice in operating the lower voltage electrical supply systems and there is not the practically universal adoption of the grounded neutral as there is in the sphere of higher voltage circuits. The advantages accruing from this method of operation have not been so striking or evident as to fully convince everybody of its desirability on low voltage systems. It has, however, been found in klydonograph surveys that arcing grounds develop on relatively small 6600 volt systems. These studies

were made in an effort to locate the cause of apparatus failures that showed evidence of voltage surges, and records obtained proved conclusively that high voltage, oscillating surges were occurring on the system of sufficient magnitude to explain insulation breakdowns. It is frequently difficult to determine the exact cause of insulation failures from an analysis of the operating conditions existing at the time of failure for it is quite possible, and it is very often the case, that the apparatus insulation will fail when conditions on the system are normal. It is a striking characteristic of solid dielectric materials that insulation may be subjected to repeated overvoltages with consequent high dielectric stresses without immediate failure of the insulation.

It is the opinion that general adoption of the stabilized neutral operation will improve the service record of apparatus connected to any voltage system. It is recognized that with this method of operation faulty circuits must be promptly disconnected from the system and that duplicate feeders would be necessary where continuous service is required. Relay systems are available for grounded neutral circuits giving a high degree of selectivity that permits of the prompt isolation of faulty circuits and protects the supply over parallel circuits. The problem is more difficult and less positive on isolated neutral circuits.

In all classes of systems there are several factors to be considered in applying a ground to the system.

LARGE GROUND CURRENT FACTORS

This is a factor which influences the protective relaying of the system using the grounded neutral. Operating experience indicates that where the relays giving line to line fault protection are to be used for line to ground fault protection, ground current should be about 3 to 5 times the current of the largest feeder to insure operation near the definite time part of the relay characteristic. If it is planned to ground the system through resistance, an allowance should be made for the resistance drop in the fault which limits the ground current especially on wood pole lines.

Where ground relays are used, the magnitude of the ground current is not important as relays of this class are of the low energy type and will operate on a very small fraction of the normal line current. It is, however, considered desirable to keep the ground current equal in magnitude to the full load current on the largest feeder to obtain the best operation of the ground relays.

SMALL GROUND CURRENT FACTORS

It is of interest to determine the minimum value of ground current which may exist for a line to ground fault and still give satisfactory operation of relays. It is also quite necessary to determine the effect this value of ground current, flowing through a loop formed by the faulted conductor and the earth return, will produce on an exposure of telephone circuit adjacent to the transmission system. This factor alone is sufficient at times to determine the maximum ground current permissible with the grounded neutral operation.

EFFECT ON SYSTEM VOLTAGE

In the event of a line to neutral short circuit, it is desirable to limit the voltage drop to a minimum so that operation of the low voltage release mechanisms of motors will be prevented and motors will not pull out due to low voltage. To accomplish this purpose, resistance is inserted in the neutral ground, the magnitude so chosen as to limit the voltage drop for a line to neutral fault and also governed by considerations imposed by the "Large" and "Small" Ground Current Factors previiously discussed.

EFFECT ON STABILITY

Recent investigations have indicated that when grounding a system through resistance, a certain value of resistance will cause a maximum KW. loss in the fault circuit. Opening of the prime-mover governor will result, and when the fault is cleared, oscillations will take place which may be sufficient to cause the system to pull out of synchronism resulting in an interruption of service.

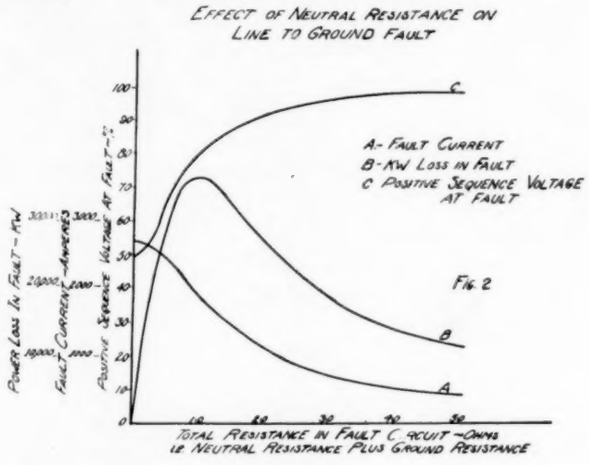

EFFECT OF NEUTRAL RESISTANCE ON LINE TO GROUND FAULT
A- FAULT CURRENT
B- KW LOSS IN FAULT
C POSITIVE SEQUENCE VOLTAGE AT FAULT
FIG. 2
TOTAL RESISTANCE IN FAULT CIRCUIT - OHMS
i.e. NEUTRAL RESISTANCE PLUS GROUND RESISTANCE

FIG. 2

The curves (see Fig. 2) illustrating the variation in positive phase sequence voltage, KW. loss in the fault circuit, and short circuit current, as ordinates plotted against resistance in the fault circuit as abscissa have been calculated for a particular system. The positive sequence voltage is the important factor which determines the system pull-out. The grounding resistor should preferably be of such a value as will cause the maximum KW. loss to occur to the right of point "A" in the region of the maximum value of positive sequence voltage.

EFFECT ON CIRCUIT BREAKERS

Since the largest percentage of faults on overhead and cable systems are of the "line to ground" type, an effort is made to limit the ground current, in order to decrease circuit breakers maintenance and render better service by minimizing disturbances.

To secure reduced ground current several methods of grounding are available.

METHODS OF GROUNDING

Generator Neutrals

When power is transmitted at generator voltage, the allowable ground current is determined by the factors of Large and Small ground current as previously pointed out.

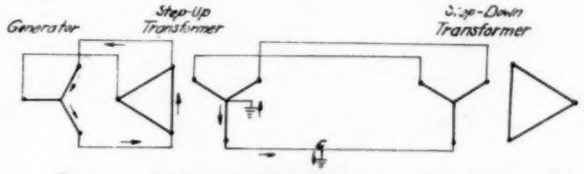
When generators are used in connection with step-up transformers only, the current required to operate the differential protection of the generators

or step-up transformers is the point that need be considered.

With machines connected in parallel on the same bus, the present day practice is to ground only one generator at a time in order to prevent circulation of triple harmonic currents between the machines. When several generators are connected, each to their own individual step-up transformer, the practice is to ground each of the generator neutrals if the transformer low voltage winding is not grounded.

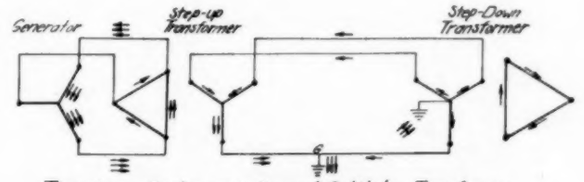
Solid Grounding

In many instances it is the practice to ground solidly the neutral of one of the machines on a bus. In this manner the cost of a neutral resistor is eliminated and there results a saving in space in the power house. This scheme is, however, subject to several disadvantages which may or may not be serious. The generators and transformers on a high voltage system will be subjected to very high cur-



Transmission System with Neutral of Step-up Transformer Grounded Fault at G. Arrows show path of ground current

Fig. 3-A



Transmission System as in A except Substation Transformer Neutral Grounded

Fig. 3-B

rents for a line to neutral fault, with consequent injurious heating for the time necessary to isolate the faulty line.

It is the consensus of opinion that grounding solidly should not be attempted on machines over 6600 volts. Above this point, it is pretty generally recognized that some device or means to limit the fault current should be inserted in the apparatus neutral.

GROUNDING THROUGH RESISTANCE

When a resistor to limit the current in the neutral is desired, a decision must be made as to the time-rating, and ohmic value of the resistance to be used.

The factors effecting these characteristics have been discussed and involve the consideration of magnitude of ground current, KW. loss in the fault, and positive sequence voltage. In addition, the apparatus heating and vibration difficulties during the single phase operation while the fault exists on the system must also be considered.

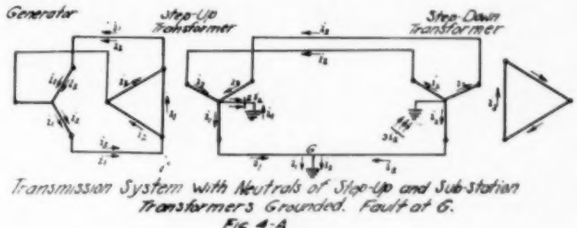
In turbine generators, rotor heating is the deciding factor. In "Salient pole machines," stator heating imposes the limiting condition.

A compromise which seems to give a satisfactory condition of operation for nearly all applications is to use a resistor of sufficient ohmic value and current carrying capacity to carry a ground current equal to full load current for one minute. Hence, this value is determined by the machine of smallest capacity on the bus with which it is to be used.

GROUNDING TRANSFORMERS

When no generator or transformer neutral is available a good system ground may be stablished by means of a grounding transformer. Such devices are often used where telephone interference would result from grounding a generator neutral.

These transformers may be of two types, star-delta, and zig-zag transformers. The zig-zag transformer application is more generally used due to its lower cost. In such a transformer one-third of the current flows in each phase winding. In a few instances resistance has been inserted in the grounding transformer neutral but in most applications



Transmission System with Neutrals of Step-Up and Sub-Station Transformers Grounded. Fault at G.

Fig. 4-A

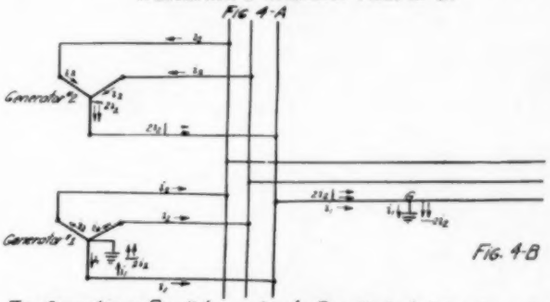


Fig. 4-B

Two Generators in Parallel on a Single Bus. Neutral of One Generator only is Grounded. Current flow in other ones as illustrated

sufficient reactance is included in the transformer design to limit the ground current to the value desired.

APPLICATION OF NEUTRAL OIL CIRCUIT BREAKER

The voltage class of the neutral oil circuit breaker should be the same as the apparatus to which the grounding apparatus is connected. The rupturing capacity should be such that if the breaker were three phase, it would rupture the maximum neutral current at line voltage.

PATH OF GROUND CURRENT FLOW

In order to illustrate the flow of ground current for line to ground faults on a grounded neutral system, several diagrams have been prepared. These diagrams, Fig. 3, A and B; Fig. 4, A and B, show the paths of ground currents and the affected phases for systems with various locations of the system ground.

SUMMARY

The purpose of this paper has been to review in a brief way, the tendency and practice of the industry in the matter of grounding. It is fairly obvious that in all cases except where it is desirable to maintain service on a single low voltage line serving important customers, that a grounded system is the ideal practice.

A grounded system increases the reliability of service because it gives the following characteristics:

a. Opportunity to use selective relaying.

b. Reduction in insulator failures due to serges, resulting in longer life to the system insulation.

c. An arcing ground is immediately converted to a line to ground fault when the relay system will clear the faulted line preventing insulator failures on other parts of the system due to surges.

The above features which are inherent in the grounded neutral system are very desirable and the tendency in power transmission and distribution is very pointedly in the direction of the grounded neutral system, resulting in increased savings to the manufacturer of electrical equipment in that insulation problems are somewhat simplified, and of course the ultimate benefit is to the central station operating company and the power consumer.

---

*The Effect of Grounded Neutral on the Efficiency of Lightning Protection Equipment**

By K. B. McEACHRON†

THE protection of service against interruption is one of the most important problems facing the operating engineer today. To the steel mill operator continuity of service is of paramount importance because of the very nature of the processes involved in the modern steel mill.

While interruptions may come from many causes, experience has shown that in the steel industry two causes are of major importance. These are lightning and switching.

Transients Due to Lightning

From a theoretical standpoint there does not seem to be any good reason for believing that the voltages due to lightning appearing on overhead conductors will depend upon whether the system neutral is grounded or not. To make this clear a brief discussion of transients due to lightning may be of value.

In general the transients appearing on overhead lines due to lightning are the result of either the release of a bound charge or a direct stroke on the line itself. The transient resulting from the release of the bound charge is the most common and will be discussed first.

A charged thunder cloud has an electrostatic field extending to the earth. As the cloud moves along, the field moves with it and when the potential gradient to the earth becomes high enough a lightning discharge will take place which suddenly changes the gradient. As such a charged cloud approaches a transmission line an electrostatic field is built up in the region of the conductors which has its greatest value when the cloud is immediately over the conductors. If no discharge from the charged cloud takes place while the conductors of the transmission line are within the region embraced by the cloud field, then the passage of such a charged cloud will not cause any appreciable rise in potential. This is true since the charges on the line of the same sign as that of the cloud are not bound by the cloud but are free to pass into other portions of the line not under the cloud and to leak over insulators to ground. After the cloud has passed over, the line again returns to its original uncharged condition. If transformer neutrals are grounded another path to ground is provided during the time that fields are slowly changing, but certainly with lines whose length greatly exceeds the length of the cloud this additional conductance to ground is not necessary to hold the line at substantially ground potential, neglecting of course the power potential of the line. Even with shorter lines the leakage will usually be sufficient to keep the lines at practically ground potential if the charged cloud does not discharge while in the neighborhood of the line.

However, if, while within the field of the cloud, the cloud discharges, causing a sudden change in field, a transient voltage will appear whose potential will be equal to the product of the height of the line and the change in potential gradient multiplied by a factor dependent on the time required for the field to change. Potentials of 2,000,000 volts have been measured during lightning storms on a 220 kv. line in Pennsylvania the conductors of which were 50 feet from the surface of the earth. It should be pointed out in this connection that the height of the line to be used in determining possible lightning potentials is the height above the true earth where the ground resistance is low. Cases have been observed where a line passing over a country in which the grounding conditions were good, had comparatively little trouble from flashover, but when the same line passed over a rocky country where the true ground may have been many feet below the surface, the number of broken insulators was very greatly increased.

On high voltage lines where considerable line insulation is required for normal voltage the number of flashovers can be decreased by the use of overhead ground wires. Keeping the transmission towers low and choosing where possible a route where the true earth is at or near the surface of the earth will aid materially in decreasing the induced potentials due to lightning and consequently the number of insulator flashovers.

From this discussion it seems clear that grounding the neutrals of transformers will not appreciably

*Presented before Pittsburgh Section, A. I. & S. E. E., February 3rd, 1928.

†Engineer, General Electric Co., Schenectady, N. Y.

alter the potentials appearing on overhead lines as the result of lightning discharges.

This is also true for direct strokes, since whether or not the neutral is grounded some one of the three conductors will always be near ground potential when the lightning discharge takes place. The system potential probably has little to do with the determination of where a direct stroke will take place and this will be especially true of low voltage systems whose potential is small compared to that of lightning. It may be that at the higher potentials the instantaneous potential on the three wires may determine which of the three will be struck.

It seems then that it may be safely stated that the transients appearing on circuits due to lightning will not be appreciably affected by grounding the neutral. While the number of insulator flashovers may not be affected by grounding the neutral the number of times that power current will follow as a result of insulator flashovers will usually be greater with the grounded neutral system. Of course such a power current follow may or may not mean a service interruption depending on how the system is set up. Some systems are so tied together with various feed-in points and so relayed that almost any single circuit may go out without causing an interruption.

Transients Due to Switching

Klydonograph studies indicate that switching surges with grounded neutral system seldom attain sufficient magnitude to be harmful.

Theoretically there seems to be no good reason for believing that switching transients will be any more dangerous with the nongrounded system than with the system where neutral is solidly grounded. If however, one line of a nongrounded system becomes grounded then the transient voltage to ground due to switching will be 1.73 times that which can occur with the grounded system, all other conditions being equal.

For a grounded neutral system the potential to ground will seldom exceed four times normal or seven times normal in an isolated neutral system with one line grounded. Under condititons existing in the steel mill where the power requirements are very severe and the load subject to wide variations, the strain on equipment due to sudden changes of load is severe. Such service giving rise to great mechanical strains may weaken the insulation so that switching transients which would not cause damage under the usual service encountered in a public utility may become a source of trouble under conditions existing in a steel mill.

Transients in Transformers

The writer is not competent to discuss in detail the merits of delta and Y connected transformers whose neutral is grounded. It is worth while however to point out some of the possibilities of the effect of transients with the different connections. When the transformers are delta connected, impulses may enter the winding from both ends and there is some evidence to indicate that potentials may be built up in the interior of the winding which under the worst conditions might equal the potentials impressed on the terminals. While it is true that the implses traveling on any one line conductor will reduce in value because of the reduction in surge impedance occurring at each corner of the delta, yet in many cases this reduction in potential will not be enough to offset the oscillations which may occur within the windings when both ends of the winding are free and ungrounded.

Although transformer failures which have been attributed to these internal oscillations are rare, yet the matter seems sufficiently important to give it consideration.

Lightning Arresters

A lightning arrester, considering the device as a whole, may be defined as a piece of apparatus connected between line and earth having the property of being substantially an insulator at normal voltage and a fairly good conductor at voltages considerably in excess of normal which again becomes an insulator when the potential returns to normal.

Just a sphere gap connected between line and ground is normally insulating and becomes conducting when the potential corresponding to its setting is reached. Such a device will protect apparatus close by, but it lacks two desirable characteristics possessed by the modern valve type arrester. First, and the more important, power current will follow if the impulse comes at the right point on the sixty cycle wave. The sphere gap has no power within itself to stop the power arc, which usually means that breakers must open and stop the flow of follow current. Second, unless the sphere gap has a certain amount of resistance in series very little of the energy of the impulse is absorbed. This energy is sent out in the line again as a reflected wave having the same crest potential as the incoming wave but negative in direction assuming that the resistance of the arc is zero. Since some energy is required by the arc the reflected wave will have a lower crest potential than the original incoming wave.

To make this matter of resistance in the arrester clear a brief discussion may not be out of place. Consider a 110 kv. transmission line whose surge impedance $\frac{V\,L}{C}$ is 500 ohms. Assume that the insulator flashover for very steep waves be taken as 1,100 kv. and that a traveling wave whose crest potential is 1,000 kv. is traveling along the line. Traveling with the impulse potential is a current wave having the same wave front and a crest value of 2,000 amperes $\frac{1{,}000{,}000}{500}$. If at the end of the line the circuit is open a reflection will take place, the current becoming zero and the potential at the open end going to double which would probably flash over an insulator at the end of the line. On the other hand if the line is connected to ground with zero resistance a current reflection takes place, the voltage at the short circuit becoming zero and the current 4,000 amperes. Again if a resistance equal to the surge impedance, 500 ohms, is connected between line and ground, no reflection of any kind will occur and the current through the resistor will be 2,000 amperes and the voltage across it will be 1,000 kv. Such a resistor has absorbed all of the energy of the impinging wave and has prevented a reflection. However an impulse of 1,000,000 volts on the 110 kv. transformer insulation

would be considered excessive and modern arresters would limit this potential to potentials of the order of 500 kv. while the current through the arrester would be of the order of 3,000 amperes. At this current the resistance of the arrester would then be 167 ohms. The effective resistance of valve type arresters is not constant being high for small currents and low for large currents.

If this same type of arrester is used on a 11,000 volt circuit it would have one-tenth of the length of active material and consequently one-tenth of the resistance and potential with a current of 3,000 amperes flowing. It is to be noted however that the impulses appearing on 11,000 volt lines based on the comparative height of lines and the insulation of wood pole construction may be considerably more than one-tenth of 1,100 kv. Although the surge impedance of the 11,000 volt circuit is not much different from that of the 110,000 volt line, yet because of the multiplicity of circuits the surge impedance in series with the arrester may be that of several lines in parallel resulting in an arrester current of perhaps 2,000 amperes under severe conditions. With this current the arrester resistance might be of the order of 20 to 25 ohms.

As the impulse current decays, the arrester resistance increases rapidly so that a very considerable portion of the energy of the incoming impulse is absorbed by the arrester, the maximum reflection being the difference between the arrester potential and that of the incoming wave or 500 kv. in case of the assumed 110 kv. line. This reflection is not high enough to do any damage and still the potential across the arrester is low enough to protect the insulation of the transformer with a good factor of safety.

Since the arrester does not reduce the potential of the impulse to zero but to some value which is safe for the insulation, it is desirable that the insulation to be protected and the arrester be kept close together. This is true because it is possible for the wave voltage passing the arrester to become nearly doubled at a transformer by reflection if they are separated a considerable distance and the transformer at the end of the circuit. No general rule can be given in complicated circuits where only one arrester is to be used to protect several pieces of apparatus, but if individual arresters are used close to the apparatus to be protected the best protection will result, other factors being equal.

Each series element of a lightning arrester of the valve type is designed to stop or prevent the flow of follow current after each impulse. If for a given number of these elements the applied system potential is greatly increased then the element may be unable to stop or prevent the continuous flow of follow current which will eventually destroy the arrester. The designer's first care is to be sure that the system to which the arrester is to be applied is such that under any condition of service the system voltage across the arrester will not exceed the rating of each element times the number of elements used.

If the system to which the arrester is being applied is not grounded or is grounded through enough resistance so that in case of a ground on one phase full line potential exists between the other two phases and ground, it is necessary to use an arrester the number of whose elements is determined by the line to line potential of the system. If, on the other hand, the system neutral is grounded at many points so that it is reasonably certain that the system neutral will always stay at earth potential, then it is possible to use an arrester based on the line to neutral voltage. The ratio of line to neutral and line to line potentials is 57 per cent. It is impracticable, however, to use an arrester for grounded neutral service which is 57 per cent of the non-grounded arrester because of the possibility of variations in system potential. Such variations are sometimes due to dropping of the load on hydro systems where the water wheel increases its speed considerably before being checked by the governors. The ratio of reduction in the number of arrester units or elements considered safe is the same ratio as in the insulation of grounded and non-grounded transformers namely $\frac{2.73}{3.46}$ or approximately 80 per cent. For most cases the arrester for thoroughly grounded neutral service can have 80 per cent of the arrester elements required for the non-grounded service which means for the same impulse current through the arrester 80 per cent of the impulse voltage thus decreasing the strain on the insulation by 20 per cent. This is a worth while gain in protection where it can be made but, as stated before, not every grounded neutral transformer can secure this increased protection, unless it is certain that the system can not lose its ground as a result of a switch operation thus becoming for a time a non-grounded system which in case of a ground on one line would be likely to prove disastrous to the grounded neutral arrester.

With a given transformer insulation appreciably better protection can be given if the system neutral is solidly grounded at many points. However each case is a special problem and must be treated as such and studied carefully. In the steel mill the power swings are large compared with many other industrial loads and whether or not all the benefits of grounding the neutral from the standpoint of the arrester could be realized would depend upon a careful analysis of each case.

Arresters applied to non-grounded circuits are occasionally subjected to arcing grounds which they will withstand for varying lengths of time depending on the arrester's characteristics, but none of the valve type arresters can be depended upon to stand up under the effects of arcing grounds for very considerable periods of time. With the grounded neutral system this difficulty disappears and the voltage to ground becomes more definite and certain. It is because of this certainty of potential that it is necessary to consider the effects of oversystem voltage. In the case of the non-grounded neutral arrester at the time of oversystem voltage one line had to be grounded to encroach on the arrester's factor of safety. The arrester on the grounded neutral circuit, however, must be capable of withstanding every oversystem voltage which may occur.

Conclusions

From the standpoint of protection the following conclusions may be drawn:

1. Transients on the line due to lightning are unaffected by grounding the neutral of the system.

2. Insulator flashover, though not any more frequent, is more likely to cause power current follow

and consequent interruption to service if the system has a grounded neutral. Special means may be employed to minimize this difficulty.

3. With the non-grounded system switching transients may have a potential 1.73 times that of the grounded system if one conductor of the non-grounded system is grounded.

4. Impulses enter both ends of the delta connected transformer which may give rise to internal oscillations within the transformer more dangerous than those in the grounded neutral transformer.

5. Lightning arresters can be made in many cases to limit the impulse voltage to 80 per cent of that of the non-grounded system, if the system is thoroughly grounded. The arrester will be both smaller and cheaper and will give proportionately better protection.

---

*Experience of a Public Utility With Grounded Neutral**

By GEORGE S. HUMPHREY†

AS a part of the discussion of the subject "Grounded Neutral," I have been asked to give the experience of the West Penn System with grounded neutral. We operate extensive transmission systems with grounded neutral, having phase voltages of 132,000, 66,000, 44,000 and 25,000, and distribution systems of 4,000 volts between phases, or 2,300 volts between phase and neutral. Our main generators also have their neutral points grounded.

Our experience in operating both without grounded neutral and with it has been more extensive on the 25,000 volt system than on any of the others.

Our first 25,000 volt lines were built in 1903 and were supplied from one generating station with two phase generators, using Scott connected step-up transformers without grounded neutral. By 1916 the 25,000 volt system had been extended until it included 615 miles of circuit (Fig. 1) supplied with power by seven generating stations with total capacity of 68,725 kilowatts, of which one station, Connellsville, contained 56,500 kilowatts. By this time the transmission lines had become so extensive that it was difficult to locate a ground, and a fault at any one point on the system would often set up voltage surges which caused additional failures at widely separated points. It was often possible to continue operation with an accidental ground at one point if the ground connection was fairly good.

However, the fault current, due to a ground was so small compared with normal load current that it was impossible to locate promptly the section of line which contained the fault and get it off the system. If the ground were not solid and arcing occurred, voltage disturbances would surge throughout the transmission system, often causing breakdowns at points distant from the point in trouble. Considerable trouble was experienced from the excess voltage impressed on lightning arresters on two phases when the third phase was grounded. These troubles became worse with each year's addition of lines until finally in 1916 it was decided to ground the neutral point at Connellsville through a resistance of 28.8 ohms.

With the neutral grounded, sufficient fault current was obtained to operate a system of over-current relays in combination with voltage relays to allow automatic sectionalizing of the trouble. Grounds could thus be quickly removed from the system and by avoiding arcing grounds and holding the neutral point approximately fixed, the high voltage surges which were formerly so troublesome were kept down so that trouble at one point would not cause breakdowns at other points as before.

The 25,000 volt interconnected system has now grown until it contains approximately 1,200 miles of circuit (Fig. 2) and is supplied with power from nine points including four generating stations, (Connellsville, Windsor, Springdale and Lake Lynn,) and five 132,000/25,000 volt step down sub-stations, (Washington, Charleroi, Kittanning, Luxor and Butler.) In order to obtain satisfactory relay operation, it is necessary to have a supply of ground fault current at every point where power load current is fed into the network. For this reason, the 25 KV neutral has been grounded at each additional point of power supply as it has been added. The neutral resistors have been reduced from 28.8 ohms to 19.2 ohms.

The 132,000 volt neutral is grounded at each generating station (Windsor, Springdale, Lake Lynn, Piney) for the same reason as the 25,000 volt system is grounded.

The best and cheapest way to ground the neutral is obviously to use transformers connected Star on the 25 KV side and ground the neutral point of the transformers; and this has been done wherever possible. However, we have found it necessary to install special grounding transformers at generating stations where we have both 25 KV and 132 KV step-up transformers.

Fig. 3 shows the phase relations and methods of grounding on our main generators, and 25,000 and 132,000 volt transmission systems.

In order to ground the 25 KV neutral at step-down 132,000/25,000 volt sub-stations we use a Star connection on the 25 KV side; and in order to avoid a Star-Star connected transformer bank we use a Delta connection on the 132 KV side. Thus our 132,000/25,000 volt step-down stations are connected Delta 132 KV to Star 25 KV. The 132 KV step-up transformers are similarly connected 11,000 volts Delta to 132,000 volts Star so that we may ground the 132,000 volt neutral. We would like also

*Presented before Pittsburgh Section, A. I. S. E. E., February 3, 1928.

†Elec. Engr., West Penn Power Co., Pittsburgh, Pa.

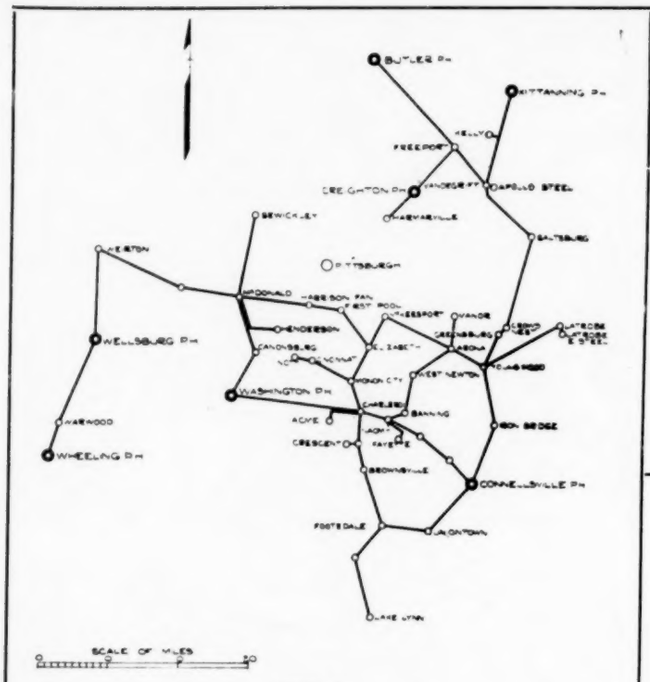


FIG. 1

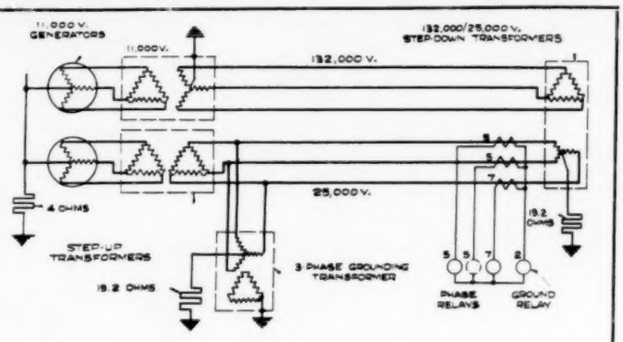


DIAGRAM SHOWING PHASE RELATIONS & NEUTRAL GROUNDING

FIG. 3

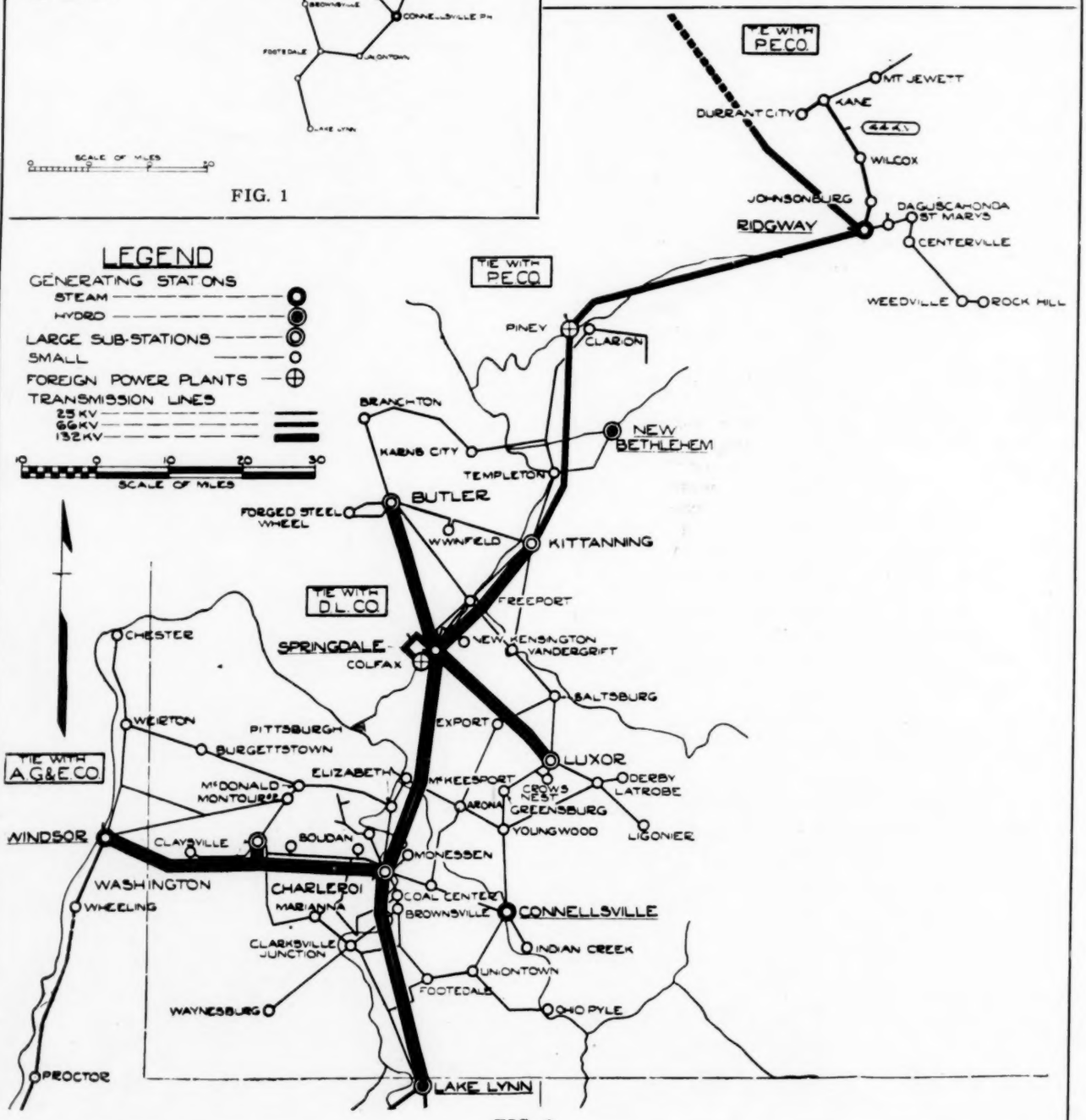


FIG. 2

to connect the 25,000 volt step-up transformers at generating stations 11,000 volts Delta to 25,000 volts Star, but we cannot do so as this would not phase in with the 25,000 volts obtained from 132 KV step-down sub-stations.

Hence, to keep in phase, our 25,000 volt step-up transformers at generating stations must be connected either Star-Star or Delta-Delta. We first met this problem at Windsor, and installed a bank of Star-Star connected 11,000/25,000 volt step-up transformers with a tertiary winding connected in Delta to keep the two neutral points approximately fixed, and to supply the triple harmonics for the magnetizing current of the Star-Star connected transformers, and thus avoid inductive interference with communication lines. This bank of transformers contained three 6,667 KV-A single phase transformers with full capacity 11,000 volt and 25,000 volt windings, Star connected, and a 2,300 volt winding of 925 KV-A capacity, Delta connected. These transformers were entirely satisfactory so far as service on the power system was concerned. However, the toll telephone lines which pass through the territory supplied from the Windsor 25,000 volt lines, picked up a great deal of noise from the harmonics in the magnetizing current of the Star-Star connected transformers which were not entirely neutralized by the current in the Delta connected tertiary winding. This winding had a capacity of 14 per cent of the rating of the transformers, which had always been considered sufficient within the previous experience of the manufacturer. However, the coils of the tertiary winding were placed together in one corner of the core of the transformer and the flux from the Delta connected tertiary apparently did not get through the whole core and left part of the triple harmonic magnetizing current to be supplied from the 25,000 volt transmission system, which in effect, supplied the triple harmonic magnetizing current in the transformer bank in parallel with the tertiary winding in the transformers. If this winding had been of no greater capacity, but had been distributed better around the core, the telephone interference possibly would not have been obtained, and surely would not have been obtained to nearly the same extent. After a long study of this trouble on the part of the engineers of the manufacturer, the American Telephone and Telegraph Company, and the Power Company, it was decided to install a special three-phase grounding transformer which is connected Star 25 KV to Delta 2,300 volts, with the 25 KV Star point grounded. This transformer has a capacity of 1,800 KV-A and has been giving satisfactory service from the standpoint of both the Power System and neighboring communication systems. Similar grounding transformers have also been installed at Springdale and Lake Lynn.

The generators are Star connected with neutral grounded through resistance of 4 ohms, operating usually with only one generator in a station grounded at the same time, if they are connected to a common generator bus. The reason for grounding the generator neutral is to keep down to a minimum the over-voltage surges in the generator, and to make it possible to disconnect it quickly in case of insulation failure. The reason for the neutral resistor is to keep the current resulting from the break-down of the insulation to a value which will not result in excess damage to the generator or over-heating in the neutral switch or its connections, or impose excess rupturing duty on the oil circuit breakers which disconnect the generator from the system.

The 66,000 volt transmission system in West Virginia and the 44,000 volt system in the vicinity of Ridgway, are both operated with Star connected transformers with dead-grounded neutral at generating stations where power is fed into the transmission lines in the same manner as our 132,000 volt system.

We have a number of 4,000 volt four-wire distribution systems, using standard 2,300 volt transformers connected between the various phases and neutral wire with neutral solidly grounded. This system affords considerable economies in the losses and cost of transformers, fuses, and lightning arrestors as compared with isolated neutral 2,300 volt systems. Furthermore, a ground caused for example by failure of an insulator or a branch of a tree, or by a wire lying on the ground, can usually be automatically disconnected at once; while with isolated neutral, a high resistance ground may stay on the system for some time without the sub-station operator even knowing the ground exists. For example, a broken live primary wire on an isolated neutral system may lie in the street for some time, and the operator know nothing of it, unless someone who sees the condition advises him. However, such a condition usually creates an unbalance between the three different phases and ground; and we have installed Star connected potential transformers with neutral grounded, and the secondaries Delta connected to operate an alarm in case of an unbalance in the primary voltages. If the operator knows that there is a ground on some circuit, he can usually discover which one it is by noting carefully the ammeter readings. If the neutral point of a distribution system is grounded and protected with ground relays, which will operate on quite small fault currents, such a line is usually automatically cut off immediately after the fault occurs.

It has been stated that a resistance of 19.2 ohms is used in each neutral ground connection on our 25,000 volt system. The purpose of this resistance is to reduce the current which results from a ground and thus minimize the blow to the system resulting from the fault. Each ground, or short circuit, places an overload with low lagging power factor, on the generators, and thus lowers the system voltage until the fault is removed. There are many more grounds than short circuits and the neutral resistor reduces the fault currents due to grounds, and thus causes less drop in voltage and less system disturbance than would occur without the resistor. Although the fault current resulting from the ground is much less than normal load current in many cases, we are able to quickly clear the faulty line by means of low energy ground relays.

There are the same reasons for using resistors in the neutral ground connections of the 132 KV and other higher voltage transmission systems, and we have often considered them for the 132 KV system. However, we do not have nearly as many grounds on the higher voltage lines, and the cost of installing the neutral resistors is very much more than on the 25 KV lines.

The relay diagram in Fig. 3 shows the manner in which a ground relay can be used to disconnect

a circuit with only a small fault current. So long as there is no fault, and all of the current is carried by the three-phase wires, no current flows in the ground relay. For example, if the load is balanced, and five amperes flows in each phase, there will be five amperes in each phase relay, and no current in the ground relay. However, if there is a ground on one phase which results in seven amperes flowing in it, while there is five amperes in each of the other phases, there will be a current of two amperes in the ground relay. We thus have an increase from zero to two amperes in the ground relay with only a comparatively small increase in phase current. We are able to disconnect our 25 KV circuits with ground currents as small as 40 amperes while the normal load currents run as high as 250 amperes.

Our experience indicates that the neutral should be grounded on main generators, and all extensive transmission and distribution systems. This aids in quickly and automatically disconnecting grounded machines or lines from the systems, and decreases the extent of the damage resulting from a ground.

For small systems, the benefits from grounding are not so pronounced, and the isolated neutral has the advantage that a line or machine may be kept in service for a time with one phase grounded. However, there is always the danger that a live wire might be in a position to injure someone, and it is better from a safety standpoint to de-energize it as soon as possible.

The Effect of Grounding on the Reliability of Relay Operation *

By E. A. HESTER AND B. M. JONES†

IT is very well understood that the advantage of grounding an electrical transmission system, either solidly or through resistance, lies in the limiting of the voltage strains upon the equipment when one of the phase conductors becomes grounded. It has been proven, by actual operating records, that grounds contribute very largely to the total number of failures.

This fact having been established, no attempt will be made in this discussion to show the relative merits or demerits of the isolated or grounded neutral system. Rather, let us consider briefly the problems met with in applying relay protection to each case and then the effect of grounding on the reliability of operation of such relays.

First, let us assume that we are called upon to apply protective relays to a system of such size and voltage as the present day operating engineer would be willing to operate ungrounded. Upon such a system three types of feeders usually will be found; namely, radial, parallel and loop. The degree of continuity of service afforded by any protective relay scheme will be determined largely by proper combination of these types of feeders and in an ungrounded system it will be possible to provide for the selection of a feeder, or section of a feeder, only when involved in a phase to phase short circuit. This comes about from the fact that a fault from any phase to ground will cause charging current only to flow, and up to the present time no practical and satisfactory relay scheme has been developed which will operate positively on charging current alone. As a matter of fact a phase to ground fault will have no noticeable effect on the service rendered unless voltage stresses of sufficient magnitude are set up, or sufficient burning occurs to cause another phase to breakdown at some place on the system. When such simultaneous breakdowns occur, it is, of course, equivalent to a phase to phase short circuit, and the phase relays should operate.

On a system which is not too complicated, the application of phase relays is fairly simple, assuming that the oil circuit breakers are capable of interrupting maximum short circuit currents. The current values upon which the relays must operate for phase to phase faults can be calculated easily and definitely, since the characteristics of the metallic or coupled circuits are fairly well fixed and the principal variable is the impedance of the fault itself. This can usually be taken care of in setting the relays by making allowance for the maximum reasonable variation. There is an exception to the foregoing in the case of faults occuring simultaneously on opposite phases at widely separated points on the system. There is then the variable impedance made up of the two faults in series plus the impedance of the ground between them. If this impedance is great enough to limit the fault current to a value too small to operate the phase relays, there is no way of removing the faulty sections until something occurs to increase the fault current to normal relay operating value. Operating experiences have shown, however, that such faults draw enough current, usually, to operate the phase relays immediately, or very soon after the fault occurs.

For radial lines the phase protection usually takes the form of simple overcurrent relays. For parallel or loop lines there are many applicable schemes, most of which involve power-directional features. It is not within our scope to go into the many factors governing the choice and applicability of these schemes. Let it be sufficient to say that, bearing the foregoing thoughts in mind and making settings for definite short circuit currents, most of the schemes used will give satisfactory results for phase to phase short circuits.

*Presented before Pittsburgh Section, A. I. & S. E. E., February 3, 1928.

†Duquesne Light Company, Pittsburgh, Pa.

Next let it be assumed that it is decided to ground the neutral of the same system which we have just considered as ungrounded. The first thing to decide is the value of the ground resistance. This may be anything from zero to a value which will limit the ground current to an amount close to full load current in any phase. It is a matter of common agreement between operating engineers that it is not wise to limit the ground current to less than full load, although there are cases on record where the value has been much less because of unusual and unanticipated earth conditions.

The factors governing the choice of neutral resistance values are many and vary with local conditions. It is not necessary to discuss them at this time since they have been rather thoroughly covered in other papers. It is well to emphasize the fact, however, that full consideration should be given to the relay problem as the degree of continuity of service rendered will depend upon the successful operation of the relays. The value should not be chosen and then an attempt made to find a relay scheme which can be added as an after-thought. Such a procedure merely invites trouble. The relay scheme should be chosen along with the method of grounding and value of the neutral resistance, the requirements for reliable relay operation being given as much weight as is consistent with other governing factors. In general, it may be said that, with modern ground relays and schemes, satisfactory operation may be secured with current values from full load up to full phase to phase short circuit current values.

The application of phase relays present practically the same problem on both grounded and ungrounded systems. Current values may be calculated with assurance that such values actually will be obtained within reasonable limits. In the case of ground currents, however, there is no such assurance since the influence of the ground return must be taken into account. The only way to be sure of the current values actually obtained is to make actual ground tests on the system after the installation is made. The relays then may be set correctly and allowance made for periodic ground impedance variations.

As an actual example of the application of ground relays to a system and the effect of a grounded neutral on the reliability of relay operation, the following is offered:

The Duquesne Light Company grounds its 66 kv. transmission system through 63 ohms at each of its two power stations. The 22 kv. transmission system is grounded through 3.75 ohms at its step-down transmission substations, of which there are a total of eight at the present time. The 11 kv. transmission system is grounded at two points through 15 ohms. The 4 kv. system is grounded solidly. This amount of resistance in the neutrals of the three transmission voltages has proven very satisfactory, although grounding solid at certain voltages is being investigated.

The value of resistance in the neutral affects correspondingly the amount of ground current that will flow, and naturally affects the schemes used for selective relaying. As an example of this point, the Duquesne Light Company, in making certain line ground relay tests several years ago on their 22kv. transmission system, found that only 128 amperes would flow with one phase grounded through four or six eight-foot ground rods and with 15 ohms in the neutral resistor at the substation. Other tests showed two or three hundred amperes. This indicates the wide range of resistance that will exist at the point of ground or in the earth—path back to the ground resistor at the substation.

There are many methods and schemes for using ground relays to take care of these conditions on systems having their transmission network grounded, either solidly or through resistors. The simplist of these is a "Y" connected system with the neutral solid. On such a system the three-phase out-going feeders require three current transformers having their secondaries connected in "star" with one overcurrent relay in each phase; and one ground relay in the star connection.

This ground relay in the star connection is for the purpose of tripping the breaker upon grounds on any phase conductor. Obviously, if the current flowing to ground is high enough to operate the phase relay of the grounded phase, it will likewise operate and tend to trip the breaker, but in this case it is very likely that the ground relay will be faster. This method of applying ground relays is quite simple, inexpensive, and reliable where the feeder is radial or radial tandem.

Another more difficult case for the application of ground relays exists where the transmission feeder starts at one base substation which has its neutral grounded and loops through several other substations, finally terminating at another base substation which has its neutral likewise grounded. This condition is met with frequently on the Duquesne Light Company System. The intermediate or loop substations consist usually of two line breakers and the transformer bank for load. The base substations have either plain overcurrent phase and ground protection similar to that described for radial lines or the combination of this and a directional feature. It will be found in most cases that the directional feature will be required.

The intermediate or loop substations must be provided always with directional phase and ground protection since power or ground current may flow in either direction and the relays must be able to discriminate.

In the case of both the base and intermediate substations, the voltage for the directional phase elements is obtained in the conventional manner. The current and directional elements are connected so that the current in the directional element usually leads the potential of this element by 30 degrees. This assures the proper operation of the directional element under all conditions of short circuit.

The directional ground relay has the main current coil and the current coil of the directional element connected in series in the "Y" point of the three current transformers, and the directional element gets its voltage by closing the delta of a small set of 110 to 110 volt potential transformers through the directional relay coil. These potential transformers are connected star-delta with the delta closed through the relay coil. The three phase leads of the "Y" side of this small transformer bank are connected to the low tension side of the main potential transformers, which are in turn connected "Y-Y". The three "Y" points of these two sets of

potential transformers are connected together and grounded solidly, thus assuring a stable neutral. After checking the operation of the directional ground relay by actually placing a ground on the transmission line and observing the direction of operation, this method assures the opening of the breaker at the proper time, and clears from the system any grounded circuit so protected.

This method of obtaining directional protection on transimssion systems with their neutarls grounded is almost universally used and has been developed within the last four or five years. Many other schemes have been tried and have been found wanting in various respects. This particular scheme is quite reliable, and the Duquesne Light Company uses it extensively on its 11 and 22 kv. transmission systems.

On the 66kv. system, the matter of relaying is somewhat simplified, although it is not really simple yet, by grounding the transmission system at each power station. The reliability of the relay operation on the 66 ring is at present of a high order, but the problem would be considerably different if the neutral was not grounded. The scheme used here, in most cases, differs from that used on the 11 and 22 kv. system in that the relays operate on the fault current flowing in the grounded conductor itself. This is accomplished by balancing the currents, which will flow in the neutrals of current transformers on two lines between the same stations and having approximately the same characteristics, against each other. The relay used has two current coils operating on the same disc and, the action being differential, the setting can be made quite sensitive.

There are on the 66 kv. system a few of the same kind of installations that are used on the 11 and 22 kv. lines. Both schemes have proven themselves to be satisfactory in actual service. While the latter is preferred because of desirable features when one line of a pair is out of service, it is somewhat more expensive.

As pointed out at your December meeting, the Duquesne Light Company have about 4500 or 5000 protective relays, and these relays are tested once every three or four months. In addition to the routine tests, once a year the directional ground relays are checked, by placing an actual ground on the system, to insure connection for the proper direction. This test is made each year prior to the beginning of the lightning season, which is about May 1.

The performance of these 4500 to 5000 protective relays for the year of 1927 was 97 per cent correct. This figure includes the performance of the relays, current transformers, battery, trip coil, auxiliary switches used in connection with the relays, the mechanical operation of the breaker and all wiring associated with the relays and their tripping circuits. The attitude is taken that the relay is not installed to perform alone as a relay mounted on the switch-board, but it expected to perform its function along with the other associated equipment to trip the breaker in case of trouble on the line, and for that reason this 97 per cent performance includes all of the equipment listed, which is the generally accepted basis of reckoning such percentage.

*Experiences in the Steel Industry With the Grounded Neutral**

By A. C. CUMMINS†

PROGRESS in the application of electricity in the steel industry has been so rapid and changes in the electric power distribution systems so frequent that it has proven extremely difficult to determine how operating conditions are affected by any single development in equipment, or changes in operating procedure.

It is therefore not a simple task to secure data to satisfactorily demonstrate whether the use of the grounded neutral has been a deciding factor in improving reliability of operation in steel mill transmission systems. The task undoubtedly would be much easier and the conclusions more definite and clear cut if it was the practice in the steel industry to keep more detailed records of electrical operating history. It is hoped that, if nothing else, what follows in this discussion may lead to fuller realization of the importance of accurate records for analyzing operating data.

The system upon which the data used in this discussion is based has, like most others, passed through a number of changes and enlargements. In order to briefly describe the conditions existing from time to time it will be necessary to briefly describe some of the improvements and the dates at which they commenced to influence operating performances.

Insulators

The original line insulators which were rated at 7500 volts. They failed so frequently that, in 1913, insulators rated at 23,000 volts were installed. An apparent improvement in service resulted. The 23,000 volt insulators were discarded in 1916. Insulators rated at 35,000 volts were substituted. Some improvement in service was undoubtedly effected by this latter change as the records referred to later in the talk will show.

Lightning Arresters

Originally the system was equipped with multiple gap lightning arresters. These arresters continued

*Presented before Pittsburgh Section A. I. & S. E. E., February 3, 1928.

†Elec. Supt., Carnegie Steel Co., Duquesne Works, Duquesne, Pa.

in service until 1913, when they were completely replaced by aluminum cell lightning arresters. The aluminum arresters reduced maintenance, afforded better protection and decreased interruptions. It was found in 1923 that the cone stacks on these aluminum arresters were worn out and they were replaced with auto-valve and oxide film arresters at that time.

Feeder Reactance

Feeder reactances were installed in 1918. The idea of maintaining bus voltage under feeder short circuit conditions, rather than furnish additional protection to oil switches, was emphasized in their selection, as the oil switches were of adequate rupturing capacity at the time. The original feeder reactors were of the three phase type.

In 1926 it was found that it would be necessary to increase the current rating of a number of the feeder circuits and hence the reactors, and for this reason it became necessary to replace several of the original reactors. Space considerations dictated that the style be changed from the three phase to the single phase type. Probably single phase reactors would have been chosen at any rate, as there had been a number of failures of three phase reactors,

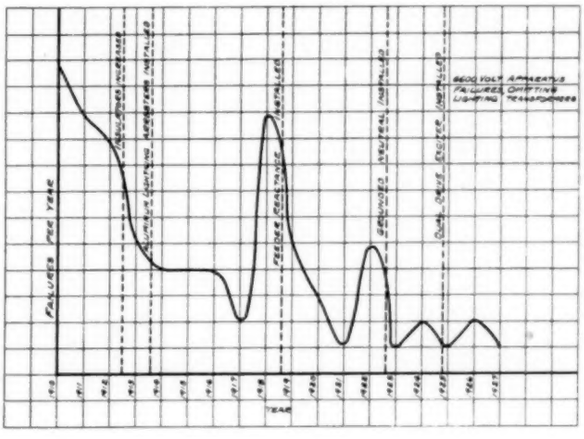


FIG. 1

largely accounted for by the fact that the installation was in a Power House where dirt was quite prevalent.

Generating Equipment

In 1910 the generating equipment on this system consisted of 7500 KVA in engine type generating units. This was increased to 26,000 KVA by the installation of turbine equipment in 1918. In 1911, interconnection at 6600 volts was started with a neighboring plant of approximately 15,000 KVA capacity at that time. This interconnection at generated voltage was continued until the present time, although the generating capacity connected at this voltage is now approximately 90,000 KVA.

Excitation

There was also a change in the method of excitation which is responsible for part of the improvement in operating results. The original exciter equipment consisted of a synchronous motor generator set which was backed up by an engine type D.C. generator at the power house, which was also used to feed into the general mill D.C. system. In 1918, a turbine driven exciter unit was installed and this was subsequently supplemented by a dual drive exciter in 1924. The dual drive exciter undoubtedly has prevented any interruptions that might be occasioned by prime mover failures on the older steam driven exciter.

In the curves accompanying this discussion, an attempt has been made to indicate failures of ap-

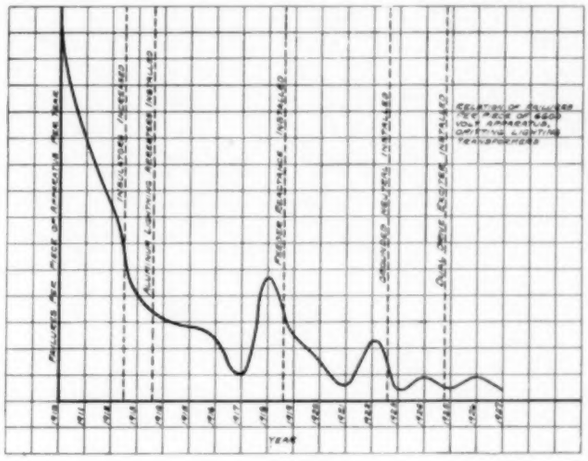


FIG. 2

paratus and production interruptions, both in relation to number of interruptions per year and interruptions in proportion to the number of pieces of 6600 volt electrical apparatus, thus expressing interruption in terms of the hazards.

Figure 1 shows an average of more than one apparatus failure per month on the 6600 volt system in 1910. Apparently increasing the size of the insulators and installing aluminum lightning ar-

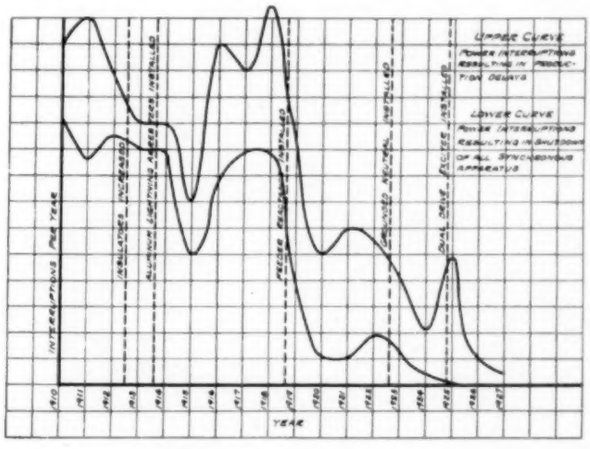


FIG. 3

resters affected a material reduction in troubles of all kinds as during the years of 1914, 1915 and 1916 the number is reduced to about one failure every four months. During 1918 the number of failures increased. It might be said in explanation that this increase was due to a series of unfortunate accidents occurring at some electric driven pumping machinery which if eliminated from the records would give 1918 a record comparable to the previous years.

During 1918 feeder reactors were installed. They undoubtedly effected a marked improvement in service. Apparatus failures were reduced in 1919 and 1920 and in all subsequent years, except 1922, 1924 and 1926.

Figure 2 illustrates the same records plotted in terms of failures per piece of 6600 volt apparatus. You will note that the service rendered on this basis, (which is the fairer basis of comparison), show a very much greater relative reduction in apparatus failures from year to year than the previous curve. It may be well to note that an expected life of 10 years before failure of any given single installation can be anticipated on a basis of the records of 1923, 1924, 1925, 1926 and 1927.

In Figure 3, two curves of power interruptions resulting in delays to production are shown. The upper being a total of all interruptions of all magnitudes, while the lower curve shows power interruptions resulting in the shutdown of all synchronous apparatus. When it is considered that power interruptions resulting from the shutdown of synchronous motor generator sets, even though the primary service may be immediately restored, result in production delays (the reason being that time lost in restarting synchronous equipment is sufficiently long

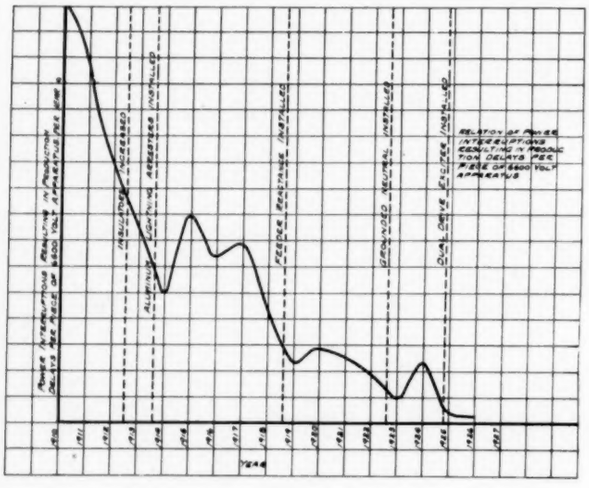


FIG. 4

to permit steel being rolled to become cold, and it therefore must be removed from the mill before operations can continue normally) the importance of successfully carrying such machinery through system disturbances without interruption can be readily appreciated. These curves show that the greatest improvement in service from the standpoint of production delays resulted after the installation of feeder reactance, because interruptions were confined to the particular equipment which was connected to one feeder or group of feeders, and the loss of synchronous load due to such disturbances was largely eliminated except in the section of the system actually in trouble. It should be particularly noted that after 1918, the curve showing the interruptions to all synchronous apparatus was greatly reduced. A word of explanation might be well at this time in regard to interruptions and production delays in the years 1921 and 1922. During these years, a series of governor failures on the turbine driven exciter at the main power house was responsible, for all interruptions, in which synchronous apparatus was lost.

Figure 4 illustrates production delays in the various years expressed in terms of the number of pieces of 6600 volt apparatus. It will be noted that expressed in this wise, the improvement in service of the 17 year period has been quite marked. It should also be stated that outages and apparatus failures due to locomotive cranes are included in all the records examined, and they are a serious liability to 100 per cent service. Such cranes frequently come in contact with transmission lines not only causing interruptions on the line directly involved, but quite frequently tear down lines and affect neighboring circuits. The influence of cranes on service was greater in the early periods shown in the curves, as each year has seen improvement in line construction, which has elevated lines beyond their reach. The time will soon be at hand when they will cease to be much of a hazard.

Grounded Neutral

The reader will find nothing in the curves just discussed to definitely demonstrate any marked improvement in service due to the grounded neutral. However, it has certainly not been detrimental or apparatus failures and power outages would increase as the installation of additional apparatus increased. Undoubtedly improvements in operating methods and more efficient protective apparatus have helped materially to effect the great improvement in service which the records indicate have been effected. Nevertheless, grounding the neutral can be considered one of the helpful additions.

It may be definitely said that the grounded neutral has accomplished three outstanding improvements, viz:

(1) It has permitted relays to function on grounds instead of short circuits, and at very much smaller current values than would have otherwise existed.

(2) Apparatus failures that have been experienced since the installation of the grounded neutral have been of very much less severity and the damage restricted to much smaller portions of the apparatus than was the previous experience. When equipment has failed, it has usually been possible to replace it in service temporarily by merely cutting coils from the windings, while previously it had usually been found necessary to resort to extensive repairs before such apparatus could be restored to service. This practice greatly facilitates meeting delivery promises to steel customers.

(3) The grounded neutral has made it possible to indefinitely lengthen elapsed time between routine insulator cleaning. This item of expense is not small, as it is frequently difficult to secure outages at convenient times and the hazards to men doing the cleaning is a consideration. Therefore the increase in time between cleaning is a factor well worthy of mention.

Something has been said about the hazards of operation with grounded neutral to telephone service. It may be said that the system referred to in this talk has been in operation several years with a quite complicated interconnected private telephone system, mounted, in some instances, on the same poles, and as far as difficulties with interference problems are concerned, it has have never been found that they were of sufficient magnitude to warrant any special devices to effect an improvement.

The Cold-Rolling of Strip Steel*

By H. C. UHL†

DESCRIPTION OF PRODUCT

Advantage of Cold Rolling
Uses of Cold Rolled Strip Steel

STRIP steel may be defined as a narrow and thin piece of steel comparatively long. In general, the term "strip steel' covers a range of material varying from ½" to 24" in width although on new mills recently constructed strip 42" wide is to be rolled. The thickness of hot strip steel varies from about .035" or even less for hoop mills to approximately ⅛" thick or even heavier on some mills classified as strip mills. The length varies up to 300 feet or more depending upon the gauge rolled.

Strip steel is of two varieties, hot rolled strip steel and cold rolled strip steel. The cold rolling mill usually uses the product from the hot strip mill and the finished thickness varies from .005" to .050" in the cold rolled product.

In recent years the production of cold rolled strip steel has been materially increased. New uses for this important material are continually being developed. This has caused cold strip steel to assume an increasingly important place in the finished steel business.

The chief advantage gained in rolling the steel cold is that in this way a highly polished and smooth surface is produced with a definite degree of hardness. By cold rolling, a more accurate and uniform gauge may be obtained, which is quite important especially for the thin sections. A thinner gauge can be obtained by cold rolling than can be obtained by hot rolling.

Large quantities of cold rolled strip steel are used by the automobile industry; for example, for fenders, rims, brake bands, etc. Much is used in the manufacture of metal buttons, parts for clocks, typewriters, bicycles, cash registers and telephones; for belt buckles, chain, ball bearing retainers, beds, stove trimmings, food chopper knives, hinges and other cutlery and hardware, electrical appliances and for innumerable other things.

Because of the fine finish imparted to the steel by the cold rolling process, this material is used extensively where it is desired to plate the material with other metals. Much is also electro-galvanized and used in the manufacture of armored cable and flexible metal hose.

It would be difficult to name all the uses for this important material.

DEFINITIONS

Classification of Cold Rolled Strip Steel as to Quality and Finish

There is quite a bit of ambiguity in the use of the terms strip, hoop, band and skelp, and it is often difficult to differentiate between hoop, band and strip steel in the thin and narrow sizes and between strip and skelp in the wider or heavier sections. Before describing cold strip steel, the various terms used for quite similar product will be defined. While there is still a divergence in the terms classified below by different manufacturers, the range of sizes frequently used at the present time for the various terms is as follows:

Hoop—No. 13 B.W. gauge and lighter, especially in narrow widths. This is rolled hot. The designation "hoop" was applied in the early days to the narrow, thin, hot rolled strip steel used for barrels, casks, buckets, etc.

Band—No. 12 B.W. gauge to 3/16" inclusive in rather narrow widths, in other words, heavier hoop, also rolled hot.

Hot Strip—Under ½" thick in any width and rolled hot on a mill designed to roll flats accurately to gauge and size.

Cold Strip—This is classified as the product obtained by cold rolling hot strip in order to obtain flat, straight strip steel of accurate gauge and size and having a definite degree of hardness and finish.

Skelp—This term is generally applied to the hot rolled product either wrought iron or steel, which is afterwards rolled into welded tubes or pipe, the gauge and width varying to suit the desired wall thickness and diameter of the finished tube or pipe.

COLD ROLLED STRIP STEEL

Cold rolled strip steel is classified as to quality in various ways by different manufacturers, there being no standard classification as to quality.

The degree of hardness will, of course, depend upon the hardness of the steel to start with and on the subsequent method of cold rolling.

Mr. W. H. Cleaver in the Iron Age, September 20th, 1923, has given a useful table of hardness classifications which is used extensively by several different manufacturers.

No. 1 Hard	Scleroscopic	hardness	approximately	40
No. 2 Half Hard	"	"	"	35
No. 3 Quarter Hard	"	"	"	30
No. 4 Soft	"	"	"	25
No. 5 Dead Soft	"	"	"	20

The hard variety has a good temper and may be used for flat work where no bending is required. Dead soft has little temper and is used for bending, drawing and forming, although for deep drawing a still softer grade is used. The intermediate sizes vary between the two limits described.

The degree of finish is also classified as follows:
A—Extra bright—extremely smooth finish.
B—Standard bright—very smooth finish.
C—Smooth bright—smooth finish.

The better degrees of finish are obtained by giving the strip a greater number of light passes for a given reduction and by the use of highly polished rolls.

PREPARATION FOR ROLLING

Pickling, Annealing, Preparation for Shipment

As has been noted previously, the raw product for the cold strip mill is usually obtained from the hot strip mill. The cold strip mills roll the product down to the annealing point, after which it is an-

*Presented before Birmingham District Section February 25, 1928.

†District Engr., General Electric Co., Atlanta, Ga.

nealed and finished further, or it is rolled to the finished size for some of the harder tempers.

The hot strip steel, if it is to be further rolled in cold strip mills, is coiled as it leaves the last stand of the hot strip mill to preserve the mild temper.

It is then recoiled by being wound loosely in the opposite direction. This prevents sticking and gives more space between turns to facilitate pickling and also removes some scale.

The steel is then pickled by being dipped in an acid solution which cleanses the surface. After a short immersion in the dilute acid solution, the steel is next immersed in water, which removes the acid remaining on the steel. Sometimes the steel is immersed twice in water, the last water being hot so that the steel dries quickly when it is removed from the bath. Sometimes the steel is dipped in a soap or lime solution which prevents rusting and also neutralizes whatever acid still remains on the steel after washing.

It is necessary that the pickling and washing be carefully done. All the scale must be removed from the metal, but the acid must not be allowed to pit the surface. Any imperfections are carried along through the subsequent cold rolling and ruin the finish. In the subsequent operations, great care is used to keep dirt from the steel.

In some plants the steel is cold rolled without first being annealed. In others the hot rolled strip is annealed before the cold rolling process is started.

The method of annealing before, during or after rolling is usually the same, although the final annealing and cooling processes may differ in some plants.

The steel is placed in an annealing furnace in covered annealing boxes having the bottom edges banked with sand to exclude the air. The steel remains in the boxes for one to one and a half days at 1200 to 1600 degs. F., depending on the composition, and is then withdrawn from the furnace and allowed to cool for several days in the covered boxes. The resulting annealed product retains its bright appearance and no scale is formed. The use of electrically heated annealing furnaces of both the non-continuous and continuous types is being given more serious consideration at this time.

The product is sometimes oiled or coated with lime to preserve the finish until the cold rolling process is started.

Cold rolling imparts a temper to the steel and for low carbon steel four passes have usually been found to be the maximum number that can be made before annealing is again required. This procedure varies for higher carbon steels, two passes sometimes being the maximum possible before reannealing is required. The method of rolling will be described later.

In one modern plant in this country, the steel is given a final annealing as above indicated. The strip is very carefully cooled in order to preserve its bright finish and to make subsequent polishing or buffing operations unnecessary. Coke gas, scrubbed to remove all sulphur, moisture, tar products or any other substance which might tarnish the strip is introduced through pipes laid under the sand into the annealing boxes immediately after their withdrawal from the furnace. The gas connection is not broken until the charge has cooled.

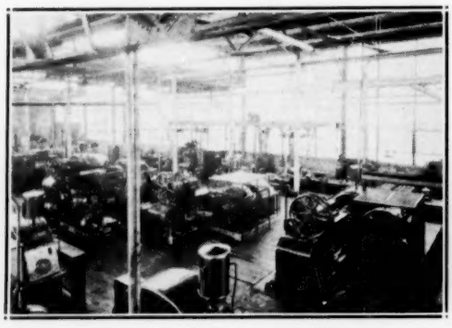


FIG. 1—Four Stands Tandem 12" Cold Strip Mill, Acme Steel Goods Company, Riverdale, Ill.

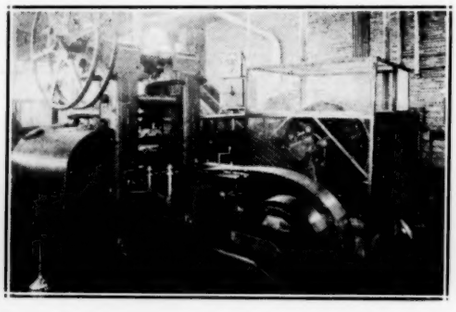


FIG. 2—Single Stand 16" Cold Strip Mill, Acme Steel Goods Co., Riverdale, Ill.

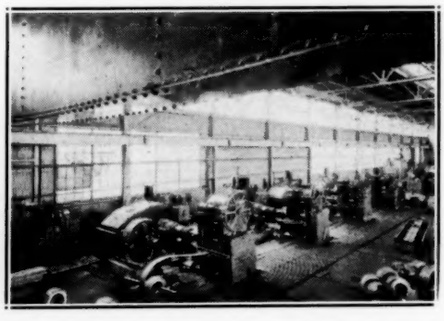


FIG. 3—Four 16" Tandem Cold Strip Mills, Detroit Steel Corporation, Detroit, Mich.

By excluding the air in this manner during cooling, the steel is protected from any possible oxidizing effects of the air as well as from tarnishing so that the high finish that is desired so much is preserved.

Unless it is necessary to give it several light finishing passes to get the proper degree of finish or hardness, or to get it accurately to the final gauge, the steel is now ready for slitting or packing. It is usually more economical to slit wide strips than to endeavor to roll the extremely narrow widths.

After the final pass, the strip may be coiled and burlaped or cut and boxed for shipment. The boxes are often lined with oiled paper, the strip itself being oiled to preserve the high finish.

TREND IN NEW MILLS

The raw product for the cold strip mill is hot rolled strip steel and consequently the quality of the cold rolled strip will depend to a large extent upon the quality of the hot strip. Any inaccuracy in the thickness of; for instance, one edge of the hot strip is carried along in the same degree through the cold rolling operations. There is very little spreading of the metal in rolling and the inaccuracies in thickness, when the strip is quite thin and wide, are not eliminated in the cold rolling process. Therefore, many of the problems and difficulties of hot strip mills are also the problems of the cold rolling mills.

The users of cold rolled strip steel are constantly requiring wider and wider sections, especially in the thin gauges. This presents a serious problem to both the hot and cold strip mills. In rolling wide cold strip steel, especially in the thin gauges, the chief difficulty is to obtain uniform gauge, because of springing of the rolls. The trend in recent mills when rolling both the hot and cold product is toward the use of large rolls to back up smaller ones which come in contact with the metal. This makes the mills 4-high when two backing up rolls are used, although the mill, of course, rolls as a 2-high mill. Sometimes six rolls are used where each working roll has two supporting rolls and is known as a Cluster mill. The backing up rolls are usually supported in roller bearings.

Because of the use of small diameter rolls in contact with the metal, the reduction in thickness can be made with a smaller amount of power and with less pressure on the rolls than would be necessary were larger diameter rolls used. By using larger diameter rolls in contact with the small active rolls, it is possible to prevent any material springing of the rolls and a more uniform thickness of the strip is therefore obtained.

The recent development of the strip method of rolling sheets of No. 16 gauge and heavier is of interest and is one of the most important advances in the trend away from the manual operation of rolling mills. We could hardly discuss the cold rolling of strip steel and not at least mention this development because it is an important extension of the developments taking place in the strip mill.

DESCRIPTION OF MILLS AND METHOD OF ROLLING

Some of the more recent cold strip mills used for rolling the wide sections are 4-high or cluster mills, but the older mills are largely 2-high mills, having only two horizontal rolls. The top roll is made adjustable by manually operated adjusting screws at each journal by which the spacing between the rolls is adjusted for different thicknesses of product.

The size of the mill is designated by the diameter and length of the roll in inches. Thus a 10″x12″ mill has rolls 10″ in diameter with a body length of 12″. In general, for the medium size mills, it may be assumed that they will roll strip as wide as the diameter of the rolls. For thicknesses less than .020″ this does not apply and the width which can be successfully rolled decreases until at .010″ it is only about one-half the roll diameter.

Cold rolled strip mills are operated either as individual stands or in tandem. Individual operation consists in rolling the steel in one mill only and then usually winding the resulting product on a reel. This steel is then rolled again on other mills or the rolls of the same mill are readjusted and the steel passed through them again. This is continued until the required gauge or finish is obtained.

When the mills are arranged to operate in tandem, the strip is passed continuously through several sets of rolls; that is, it is rolled in one set of rolls and then passes directly into the next roll stand, and so on. The metal is thus in several or all stands at one time. The steel is usually started into each stand of rolls by hand, the roller gripping the strip as it comes from the reel or from the previous stand and guiding it into the rolls. It is reeled only after it leaves the last stand.

The steel is usually slack between stands, although some mills are designed to maintain tension in the steel between stands and some are designed to reel the steel from the last stand under tension. Friction clutches have usually been used on the reel drives although electrically operated and controlled reels are used in some cases.

The maximum rolling speed for cold strip mills varies from 80 to 250 feet per minute up to as high as 350 feet per minute in some modern mills. In tandem mills, the rolling speed of the steel, of course, increases as the steel is reduced in section and the speeds above noted are for the last stand. Groups of four stands are frequently operated in tandem, four passes being sufficient to obtain a 50 per cent reduction on the usual grade of low carbon steel. If further reduction is required, the metal is annealed before the next cold rolling process is started. The mills are also arranged to operate in different tandem groups and as individual stands when so desired. This is necessary to meet the wide range of specifications as to finish, hardness and gauge.

A separate additional stand operating individually is often used through which one or two passes are made following annealing. These passes are in the nature of finishing passes to obtain the proper quality, finish and accurate gauge required in the finished product.

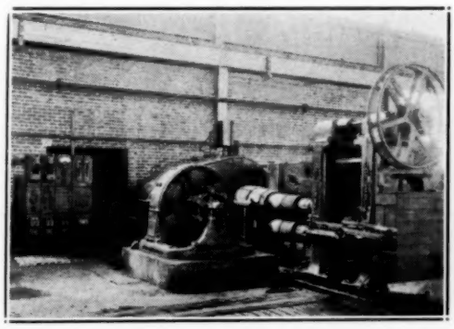


FIG. 4—16″ Cold Strip Mill, Detroit Steel Corp., Detroit, Mich.

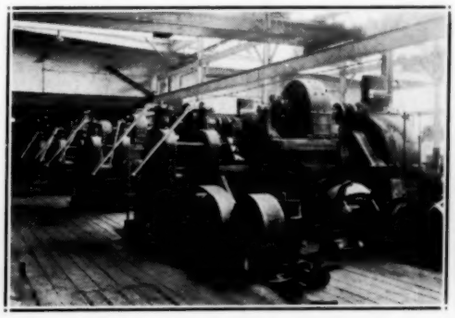


FIG. 5—16″ Cold Strip Mills, Griffin Manufacturing Company, Erie, Pa.

FIG. 6—16″ Cold Strip Mills, Griffin Manufacturing Company, Erie, Pa.

ELECTRICAL EQUIPMENT FOR COLD ROLLED STRIP STEEL MILLS

Motors and Control

A. Induction motors for cold rolled strip steel mills

Individual stands of cold strip mills are sometimes driven by constant speed induction motors of the wound rotor type. Constant speed drives are possible where a single product or a very small range of products will be rolled on a given stand or on several stands where the strip is not in two or more stands simultaneously.

The only special requirement of a wound rotor induction motor drive as described above is to be sure that sufficient torque is available to start the mill with metal in it.

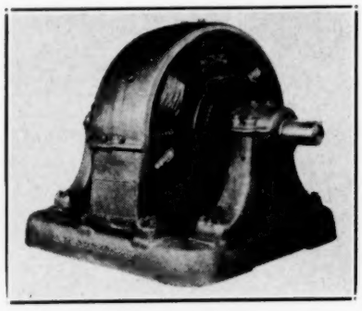


FIG. 7—250 HP. Direct Current Motor with 2 bearings and base.

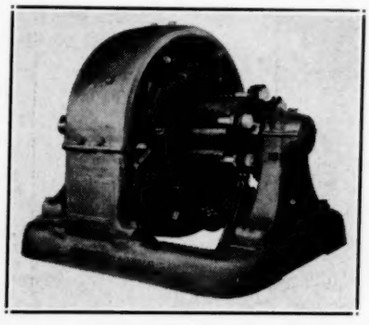


FIG. 8—250 HP Direct Current Motor with 2 bearings and base.

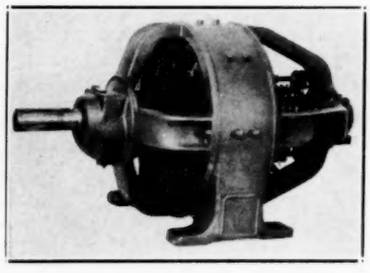


FIG. 9—60 HP. Shunt Wound Motor.

If a wide range of products are to be rolled or if tandem continuous rolling is contemplated, constant speed motors will not ordinarily be satisfactory.

B. Direct Current motors for cold rolled strip steel mills

On most cold strip mills adjustable speed direct current motors are required. They are practically essential where tandem operation is desired with steel in two or more stands simultaneously. The speeds of the various stands may then be adjusted with respect to each other. Adjustable speed is also necessary for a single stand where a large range of sizes is to be rolled, as this makes it possible to obtain the best rolling speeds for various thicknesses to give the highest quality of product.

The motors are usually connected to each mill stand through suitable reduction gears.

A line of adjustable speed direct current motors and necessary control apparatus has been standardized for this service. Occasionally, larger motors or motors with different speeds or voltage or with more speed range are required to meet special conditions.

The standardized line of motors are direct current machines, 230 volts with basic speed 400 RPM and with speed adjustment by motor field control up to 800 RPM. There is a tendency recently toward the use of wider speed range motors, speeds from 400 to 1200 RPM being used on many new mills. The motor size is usually specified by the mill builder and all stands of one size or group are driven by motors of the same rating.

The motors at present developed for this type of service by the General Electric Company are in the following horsepower sizes, 25, 35, 50, 75, 100, 125, 150, 200, 250, 300, 400 and 500. Still larger sizes may readily be built.

The motors from 25 to 150 HP inclusive are of the shield type of construction with a split end shield on the coupling end, without base and with shaft extended on one end for coupling to a gear unit. The motors 200 HP and larger are of the pedestal type of construction and are provided with a base and with shaft extended on one end for coupling to a gear unit.

All the motors are rated as open motors on the basis of 40 deg. C. rise on the armature and fields at normal load for continuous operation with higher temperature rise on the commutators as is usual.

All motors are good for maximum momentary loads in amperes of at least 200 per cent of normal current.

Where direct current motors are used for cold strip mills, it is quite frequently necessary to provide means for converting the alternating current supply to direct current for driving these motors. This requires the usual apparatus—standard motor generators or synchronous converters with switchboard equipment and with transformers where necessary.

WARD-LEONARD CONTROL

A tandem group driven from one motor generator may take advantage of Ward-Leonard control. This system requires separate excitation for the generator and also for the motors driving the mills. The motors are connected to the dead generator busses and are started by building up the line voltage by generator field control with full field on the motors. When the motors are up to speed, the speed of the individual motors may then be adjusted by means of their motor field rheostats. There is no reason, when using Ward-Leonard control, why the motors cannot be operated at lower speeds than basic speed by simply reducing the line voltage by adjusting the generator field rheostat. In this manner the whole group of motors may be operated at slow speeds and the speed of the whole group varied as desired up to basic speed by generator field control. For speeds above basic speed, motor field control may be used to increase the speed of the motors further. A wider speed range may thus be obtained, but each group of motors will require a separate motor generator set. In general, this type of con-

trol is practicable in special cases where conditions warrant it.

CONTROL FOR COLD STRIP MILL MOTORS IN USUAL SIZES

The type of control in general use for the motors in standard sizes listed in the preceding includes a floor mounted panel for each motor on which the following is mounted: line switch, field reversing and control switch with fuses and field discharge resistor, overload relays, field protective relay, full field relay and field accelerating relay if speed range is great, necessary time limit accelerating relays, line contactor, accelerating contactors, under-voltage protective and control contactor for equipments operating in tandem and jogging contactor on equipments operating in tandem.

Where the motor is one of a number driving mills operating in tandem, double throw transfer switches are mounted on each panel which are so connected that when they are thrown in one direction, the equipment will operate as an independent

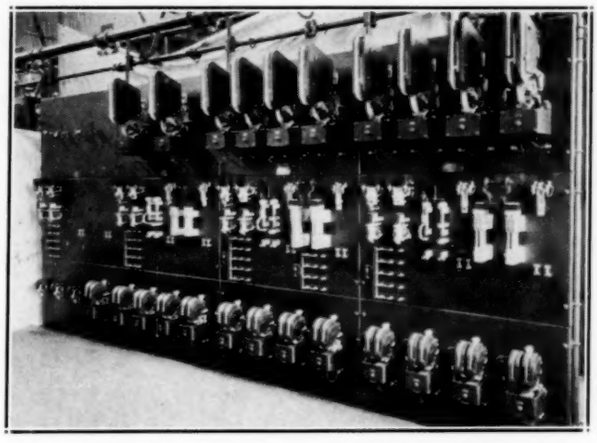


FIG. 10—Control Panel, Four Stand Cold Rod Strip Mill.

unit; when thrown in the other direction, tandem operation may be obtained in certain predetermined groups.

When the mill consists of two, three or four equipments they may be arranged to operate in tandem. When two equipments comprise the cold rolling mill they are arranged to operate either individually or both in tandem. When three equipments comprise the mill they are arranged to operate as three individual units and also so that No. 1, No. 2 and No. 3 may be operated in a tandem group or No. 1 and No. 2, or No. 2 and No. 3 may be operated in a tandem group. When four equipments are used on the cold strip mill, the control is arranged so that all four equipments may be operated as individual units and so that they may be operated in the following tandem groups:

No. 1, No. 2, No. 3 and No. 4 in tandem.
No. 1, No. 2 and No. 3 in tandem.
No. 2, No. 3 and No. 4 in tandem.
No. 1 and No. 2 in tandem.
No. 3 and No. 4 in tandem.

The motors not in the tandem group may be operated individually. Three of the four control panels for the above arrangement will be duplicates except in the panel wiring and will each have one transfer switch, the other panel will have two transfer switches.

The above arrangement, for four equipments in tandem, has been found satisfactory in service to meet all the desired conditions of rolling.

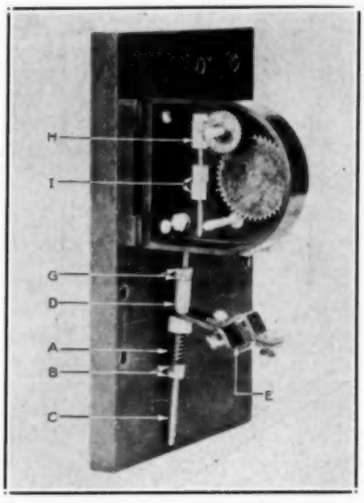


FIG. 11—Definite Time Interlock, Open View.

In addition to the control panels described above, the following is also provided:

(1) Intermittent duty starting resistor for each motor.
(1) Manually operated field rheostat for each motor with cover over the front dial.
(1) "Start, Jog, Stop" push button station for each motor.
(1) Ammeter panel for each motor.

Manually operated field rheostats are usually used although motor operated field rheostats may be furnished if desired. The number of speed points will, of course, depend upon the speed range re-

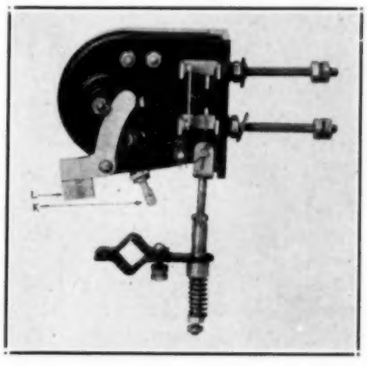


FIG. 12—Definite Time Interlock, Normally Closed.

quired on the motors and upon the conditions of rolling. In some cases extremely fine speed adjustment may be desired.

The ammeters may be mounted on the control panels, but most mills desire to have the ammeters mounted on a separate base for mounting near the motor.

The arrangement usually desired on these mills is to mount the manually operated field rheostat, the push button station and the ammeter at each mill so that the motors may be started and stopped, the speed controlled and the load observed at one point most convenient for the operator.

Dynamic braking is usually not required on cold strip mill equipments. When metal is in the rolls, the motors will stop quickly when it is necessary to stop them for any reason, and if no metal is in the rolls coasting is usually not objectionable. Dynamic braking may be incorporated in these equipments if so desired, but it is usually considered unnecessary.

In the event that compound wound motors are used in special cases, the use of a single pole, single throw switch of line capacity is advisable on each equipment in order that the series field of the motor may be short circuited whenever the motor is to be operated in the reverse direction.

The control equipment as outlined provides overload protection in both lines and undervoltage protection. When the equipment is shut down, both sides of the motor armature and the starting resistor will be disconnected from the power line.

The acceleration of the motor is controlled by definite time relays which insures that the motor will start in a definite time regardless of the load. This is, of course, very important when starting with metal in the rolls. These relays, known as CR-2953 definite time interlocks, obtain their time delay by an ingenious application of simple mechanical principles, no dash pots or similar devices being used on the relays.

Full field is held on the motor during acceleration to basic speed. At this point, the full field relay drops out and the motor will then accelerate in one step to the speed determined by the setting of the motor field rheostat. If the speed range is greater than two to one, it is frequently advisable to use a field accelerating relay in addition to the full field relay so that acceleration will be in two steps instead of one, after the field rheostat is placed in the circuit.

The equipment is protected against loss of shunt field on the motor by means of the field protective relay, which opens the control circuit on failure of the motor field and shuts the equipment down.

Provision for reversing is provided on each panel. It is necessary to reverse these motors only infrequently with motor practically at standstill, whenever it is desired to back steel out of the rolls.

For tandem operation, the pressing of any "start" or "stop" button of the equipments being operated in tandem will start or stop the tandem group and the tripping of any overload relay, field protective relay, etc., will shut down the tandem group. When starting a tandem group from any "start" push button, the motors will start in the proper sequence, which, of course, depends upon the position of the transfer switches; that is, the first motor will start first and, as soon as it has fully accelerated, the next motor will automatically start, etc. The "start" push button need be held down only until the undervoltage contactors of the tandem group have picked up and need not be held down until all the motors have accelerated to full speed.

The pressing of the "jog" button will start up the motor corresponding to the "jog" button and all succeeding motors operating in tandem in that particular group in proper sequence. All preceding motors will remain at standstill. Whenever the "jog" button is released, all equipments will shut down again.

In the event that individual operation is desired on all motors or on motors not used in the particular tandem group, the operation of the push buttons is then such that only the individual motor will be operated from the particular push button station.

MOTOR SIZES REQUIRED FOR VARIOUS SIZES OF MILLS

It is difficult to definitely classify mill sizes and required motor horsepower. The mill manufacturer usually specifies the horsepower required for cold strip mill drives and various mill builders have different standards.

In checking over a large number of cold strip mill drives where in the cases listed, the mill size was available, it has been found that the following size motors have been used for certain roll diameters with slightly varying length of rolls.

Roll Diam.	Motor H.P.	No. Drives Checked
8″	50 to 75	9
10″	75 to 100	14
12″	125 to 150	16
16″	250	21
20″	375	2

The above checks fairly closely with the data for calculating the horsepower that has been used by various manufacturers, which takes into account the roll diameter, total length or face of roll and the finishing speed of the steel.

With the rapid advent of the newer mills with rolls of small diameter backed up by larger rolls, the above data will not hold and data has not yet been accumulated for classifying the mill size and required motor horsepower for these newer arrangements, which are, of course, used especially for the wider sections.

DRIVES FOR REELS

After the final pass, the steel strip is usually wound tightly in the form of a coil, tension being maintained and adjusted between the last stand and the reel by means of a friction clutch. Recently reel drives which automatically hold a uniform tension throughout the winding of the strip have been developed.

It is evident that as the strip is coiled on the reel, the effective diameter of the reel will increase. If the lineal speed of the strip coming from the last stand of the mill is approximately constant, the speed of the reel must decrease as the steel builds up on the reel, in order to maintain a uniform tension.

Thus, if the delivery speed of the strip from the last stand is constant and if it is desired to maintain a uniform tension on the strip, work is being done at a constant rate and thus, if constant horsepower input to the reel motor is maintained, this will accomplish the desired purpose. Since adjustable speed motors are used for driving the rolls, the delivery speed of the strip from the last stand varies. This means that to maintain a uniform

tension on the strip being reeled under all conditions, provision must be made so that not only constant horsepower input to the motor driving the reel must be maintained when the speed of the strip from the last stand is constant, but also that provision must be made to accommodate different delivery speeds from the last stand.

It is, of course, desirable when starting the reels that the accumulation be taken up rapidly, that tension be maintained in the strip when the mill is stopped and tension held when the mill is again being started. The amount of tension held in the strip should also be adjustable and this value held throughout the entire coiling of the strip on the reel. In addition to these features, it is desirable to arrange the reel so that it may be operated independently of the last stand.

Various schemes have been developed for this drive by different manufacturers which are in successful operation.

CONCLUSION

Comparatively little has been written on the subject of cold rolling of strip steel and it was not the purpose of the writer to present a treatise on this subject. In this paper the object has been to give a general idea of what the product is, why and how it is used, the methods usually used in treating and rolling it, a general idea of the improvements being made in the modern methods and mills and a description of the electrical equipment usually used for these mills. No attempt has been made to go into great detail in describing many of the processes or modifications used in some plants in special cases.

DISCUSSION

W. W. Garrett*: For what purpose is hydrogen sometimes used in the cooling process after hot strip rolling?

H. C. Uhl: Hydrogen has been used in the final annealing process instead of coke gas. The hydrogen is introduced into the annealing boxes after their withdrawal from the furnace and an atmosphere of hydrogen is kept in these boxes during the entire cooling process. The function of the hydrogen is merely to give a reducing medium instead of an oxidizing medium which would be present if air were left in the annealing boxes. It, therefore, has the same function as the coke gas to preserve the fine finish on the strip. This has been described in the August, 1927, issue of the Iron & Steel Engineer.

J. E. Sayre†: Can the time limit of General Electric mechanical relays be changed by changing the gear ratio?

H. C. Uhl: There is a possibility of change by this method, although the adjustment provided on the relay by means of the change in rack travel or change in position of pendulum weights will give a time adjustment range of from ½ to 4 seconds. Another arrangement of the relay as shown on the slide will give another time adjustment which is used for special purposes.

J. E. Sayer: What is the average size of rod or billet used for cold rolling or strip?

H. C. Uhl: The raw product of the cold strip mill is usually obtained from the hot strip mill and is usually not classified as a rod or billet. It is usually in the form of strip when entering the cold strip mill for the first time. The size billet used for the hot strip mill varies, depending upon the width and final thickness desired.

A. L. Lemon*: Do you think that continuous rolling will be developed in the near future?

H. C. Uhl: I presume you refer to sheets. A very interesting article by Mr. Shover was published in the January, 1928, issue of the Iron & Steel Engineer, which described the strip method of rolling sheets. I believe that very much progress has already been made in continuously rolling sheets and that more progress will be made in the future with regard to rolling the thinner gauges.

A. L. Lemon: What is the purpose and advantage of cold rolling?

H. C. Uhl: As was described in the paper, the advantage of cold rolling is to obtain a highly polished and smooth finish with a definite degree of hardness. A more accurate and uniform and thinner gauge may be obtained by cold rolling than by hot rolling. As you know, sheets also are usually given the final rolling cold to give a better finish and to obtain the final accurate gauge.

S. C. Ebbert: Is hot strip reeled edgewise after it leaves the rolls?

H. C. Uhl: In the mill I mentioned where narrow hot strip or hoop was rolled instead of obtaining the narrow widths by slitting, the hot strip was carried down the table on edge, and was also picked up by the reel which operated in a horizontal plane and, therefore, did not twist the strip in reeling, but wound it in the form of a coil in the horizontal plane.

A. L. Lemon: Please give a brief explanation of torque versus current in D. C. motor speed control.

H. C. Uhl: In direct current motors the torque exerted by the motor is, for all practical purposes, proportional to the product of the flux and the armature current. The horsepower is proportional to the product of the torque and speed. Therefore, assuming constant speed with constant flux; that is, constant field excitation, the armature current would be a measure of the torque exerted by the motor, and this current would change as the torque exerted by the motor changes.

In case the field excitation and consequently the flux, is held constant and the speed of the motor is changed by varying the armature voltage, which is the method used in Ward Leonard control, a reduction in armature voltage will give reduced speed. This arrangement gives an inherently constant torque drive; that is, the horsepower, for normal motor rating, will be reduced directly as the speed is reduced. For the conditions of constant torque approximately normal armature current would be held for all speeds.

In the event that the field is strengthened to obtain lower speeds and full armature voltage is maintained, a given armature current will produce, with heavier field, a greater torque than it would with weaker field. This arrangement gives an inherently constant horsepower drive; that is, the horsepower for normal motor rating will be the same at all operating speeds. For the conditions of constant horsepower, the same armature current produces increased torque at the lower speeds.

---

*Engr. Dept., Tenn. Coal, Iron & R. R. Co., Fairfield Ala.

†Elec. Dept., Tenn. Coal, Iron & R. R. Co., Ensley, Ala.

*Elec. Engr., General Machinery Co., Birmingham, Ala.

*Discussion on Grounded Neutral**

By Membership

Elbert Lewis†: In this discussion about grounding the neutral of steel mill power system might say that for the past 22 years it has been our practice to have two voltmeters that are connected to the secondaries of two shunt transformers having their primary terminals connected in series across the two outside busses, with the middle point grounded. So long as the 2200 volt system is clear from grounds the two voltmeters are balanced at 55 volts. If phase A becomes grounded its voltmeter reads O, while the one connected to phase C will read 110 volts, or the opposite. In case phase C is grounded, and if the ground is on phase B each voltmeter will read 110 volts. If the ground is intermittent, periodical or of high resistance, these instruments are a decided help in determining the nature of the fault and getting it located. These voltmeters are located on the switchboard where they are observed by the operator the same as the station bus instruments.

When there is a ground disturbance indicated all stations are immediately called to learn if any motor or generator has just been started, if so, it is taken off to see if it is the cause. After this the next move is to start at once to disconnect from the system, one at a time, every generator, exciter roll motor and sub-station set, and if wet weather, linemen are started out in search for arcing grounds.

The strict enforcement of this rule has, in practically every case, made it possible to definitely locate and clear even the slightest of ground disturbances, while still affecting but the one phase.

As demonstrated in a few cases I have in mind, such as finding wire down on crossarm, leaking strain insulator in very dirty location, or two instances of generator trouble, one a turbo unit and the other a slow speed generator where but a single piece of lamination had cut a very slight groove through the insulation, causing only an intermittent ground when taken off the system. The defective coil was located with a test set and lifted only enough to reinsulate the punctured spot and remove the loose section of lamination. All the generators are now protected by differential relays, which have proven to be very effective and highly satisfactory, but would not operate on such slight grounds as above described.

There has been a few times that a 2200 volt motor, driving a Structural Mill hot saw, has been found to be grounded, but started up again and allowed to run an hour or so then change the motor during a roll change. With a grounded neutral it would not be possible to do this or to locate ground disturbances before they actually cause little, if any, damage to the equipment, or interruption of the Power System.

We, therefore, do not believe that it would be of any advantage to replace our present system with the grounding of the neutral.

E. C. Marshall*: I haven't heard any speakers comment as to what protection they have actually experienced. By that I mean on systems that have been grounded, have been protected by circuit breakers, did the breakers function; was the desired protection obtained?

With the system grounded will difficulty be experienced due to unbalanced phase currents caused by single phase loads, cutting out of coils in large motor windings or otherwise?

It is understood protection is being afforded by balanced currents which very often is not the true line condition.

R. S. Shoemaker†: I imagine we are with the majority. All of our plants are ungrounded. We are contemplating a large installation but we are not quite sure what we shall do, whether ground or not. After surveying a number of plants we discovered most plants were not grounded and seemed to be going along fairly well; so we have ordered transformers and have them arranged so we can add grounding transformers if we find the trend of things is that way.

W. E. Miller‡: There seems to be a difference of opinion as to whether or not the ground wire is an advantage. At our Johnstown Plant, the 6600 volt interconnecting bus lines consist of two circuits of three 1,000,000 CM cables about 15,000 feet long, one section of which is covered by a ground wire, and another section is not. Two cases of flash overs have occurred on the section of line having the ground wire while no flash overs have occurred on the uncovered section. In this case, it would be rather difficult to prove the advantage of a ground wire.

R. D. Evans§: The question of whether the power system should be operated with a free neutral or whether the neutral should be grounded has been settled in the central station industry as Mr. Hanker has pointed out. The answer may be stated in this way: A power system should be grounded whenever its extensiveness becomes such that arcing grounds will be encountered. Now the question confronting the electrical engineers of the steel plant is whether his system has grown to such a size that grounding of the neutral of the system would improve the continuity of service and lessen the failure of apparatus. This question is of interest to the electrical manufacturer with respect to the performance of his apparatus. The question however, is primarily an operating problem to be decided for the individual system because the principal considerations are those bearing on continuity of service.

Mr. Cummins has presented interesting data on the effects of various changes in his power system

*Original papers by Messrs. Pilliod, Hanker, McEachron, Humphrey, Hester, Jones and Cummins appear on front page of this issue.

†Asst. Elec. Engr., Illinois Steel Co., South Chicago, Ill.

*Elec. Supt., Youngstown Sheet & Tube Co., Indiana Harbor, Ind.

†Supt. Maintenance, American Rolling Mills Co., Middletown, Ohio.

‡Elec. Supt., Bethlehem Steel Co., Johnstown, Pa.

§Engr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

on the interruption record at the Duquesne plant. However, as he pointed out, these records, while not inconsistent with the theory of grounding, do not in themselves prove that grounding is advantageous, that is, the data presented is not conclusive with respect to the advantages or disadvantages of grounding. Mr. Cummins mentioned in the case of their own system the decision to ground the neutral followed a series of simultaneous failures or experiences which are commonly recognized as the effect of arcing grounds. It is this particular kind of trouble which, when it becomes prevalent, has forced the grounding of practically every large transmission system in the central station industry. It appeals to me that data which shows the prevalence of troubles of this sort is the most pertinent to the problem under consideration. If grounding is an operating problem as has been indicated, then it would appear particularly desirable to urge the compilation of records from the standpoint of showing the approximate simultaneous occurrence of failures for the individual system. Such a curve might be obtained from the percentage of failures which occur simultaneously to the total number of failures, plotting the data for each year for a suitable subdivision. Such percentage of simultaneous failures could include those occurring within 24 hours from the failure, excluding those which can definitely be established as unrelated to any arcing ground phenomena. Such data might be plotted so as to show the occurrence of failures of this type with respect to the capacity of the system or the extent of the system. Such data should, of course, include all parts of the system electrically tied together independent of whether apparatus would be included in other steel plants with which an interconnection might exist.

The paper by Mr. Pilliod deals with the problem of co-ordinating electric power systems and communication systems when they traverse the same general territory. The problem involves three principal factors, namely: (1) influence of the power system, (2) the coupling of power and communication circuits, (3) the susceptedness of the communication circuit. Interference is not due to any one of these factors alone but rather it is due to all of these factors in varying degrees. In general interference may be avoided by reducing the effect of any of these factors, for example, it may be accomplished (1) by modification of the power system to limit its influence on the communication circuit, (2) separation of the two circuits to reduce their couping, (3) modification of the communication system to reduce its susceptedness to the influence of the power system.

In the presentation Mr. Pilliod described how the design or layout of power systems affect the influence on communication systems. He also mentioned separation of the two types of circuits which is a most desirable and practical method for the cases involving heavy power lines and through telephone or telegraph circuits. I wish to point out that in the complete paper Mr. Pilliod lists a number of interference prevention measures for use on communication circuits. It is these measures which Mr. Pilliod did not mention in the presentation, presumably for lack of time, that can be and actually are applied to supervisory circuits to insure their operation under conditions which would otherwise lead to interference with service. It is recognized that there are intense differences between a private communication system and one providing public service on a nation wide scale and these differences have an important bearing on their applicability for the solution of specific cases of interference.

While it is theoretically possible to solve coordination problems in any one of the three ways mentioned previously, it will of course be understood that the methods are more economical or practical from an operating standpoint. Usually the best solution is the combination of two, and not infrequently of all three, of these methods. For these reasons co-operation and advanced training usually leads to a solution that is economical and satisfactory to all parties concerned.

E. G. Merrick*: Comparative data showing service interruptions with the neutral ungrounded and grounded may possible be somewhat misleading, unless accompanied by a careful analysis of what actually transpired. Such an analysis was prevented in Mr. Cummins' paper by the brevity of the available operating records.

With the neutral ungrounded, abnormal voltages due to "grounds" occur simultaneously throughout the system; the magnitude of these transients may vary through a wide range, depending on various conditions. Experience and tests have demonstrated that potentials of several times normal value are possible, but it does not necessarily follow that these extreme values, dangerous to equipment, are realized every time a "ground" occurs in the system.

With the neutral grounded, every "ground" constitutes a short circuit which must be immediately cleared by the opening of one or more switches. While the danger of damage to equipment has been reduced, it is obviously possible that the number of service interruptions may be actually increased, unless this is prevented by suitable means.

The prevention of undesirable interruptions in the grounded neutral system involves duplicate feeders to important loads and perhaps greater refinements in the scheme of relay protection, whether the corresponding expense is warranted depends upon the valuation placed on continuity of service.

In arriving at a decision regarding the relative merits of grounded neutral versus ungrounded neutral systems, the very general practice of the Utility Companies in favor of the former should not be overlooked; this practice has been justified by very definite reductions in apparatus failures.

The possibility of excessive potentials in the extensive, high voltage networks of the Utility Companies, with ungrounded neutral, may be greater than in the systems of the average industrial plants. Evidence of dangerous, abnormal potentials in the latter are, however, not lacking and the question "to ground or not to ground?" is, therefore, one which the Iron & Steel Electrical Engineers cannot safely avoid.

*Engineer, General Electric Co., Schenectady, N. Y.

ARC WELDING AND THE NEW MARKET FOR ROLLING MILL SHAPES

(Continued from page III)

cussed it to a limited extent, but it might be further said that to use cast iron means a great investment in foundry equipment, patterns and buildings, it implies the carrying of a heavy stock of current and superseded parts and the tying up of working capital in things that are inactive and profitless. The only capital investment needed when arc welding is employed is for welding equipment and a stock of standard structural shapes.

It has been actually demonstrated by one manufacturer that his inventory of steel is less than 11% of the amount that formerly represented his investment in iron castings and patterns. Beside this there is offered the inducement of greater production with the same floor space. It has been shown that the average shop can at least double its production by using arc welded steel.

It would be impossible in the scope of this article, for us to even enumerate the products now being manufactured of commercial steel by arc welding. And though generalities are vague and dangerous we do not hesitate to say there is almost no considerable manufacturing enterprise in which it is not used to some extent. Scarcely a day passes but some new application is brought to our notice and there is hardly a good application that does not involve the replacement of castings with structural steel.

The largest electrical manufacturing company in this country states that they are saving more than 1,000,000 dollars a year by the use of arc welded steel and are making this saving on less than 3% of their product. In general it may be fairly said that the cost of all machines which are now made of castings may be reduced by an average of at least 20%. A company, one of the pioneers in arc welding, has been able to effect a sweeping changeover from castings to arc welded steel and realize a reduction of more than 50% in the cost of fabrication.

What we have said should surely indicate the direction in which manufacturing is at present pointed. How speedily it will advance in that direction depends to a great degree on the energy with which the advocates of steel and arc welding advance its cause. Economic necessity will do much but it cannot do all. The steel men through out the world must complement its working by assisting in the conversion. In proof that such assistance as they render will be pleasantly to their profit, we quote again the rough expenditure that was made for castings in the year 1927—$705,097,710.

Items of Interest

When the Cutter Electrical and Manufacturing Company of Philadelphia, manufacturers of I-T-E Circuit Breakers and U-Re-Lites for 40 years, recently decided to change its name to the I-T-E Circuit Breaker Company, it was felt that there must be a significant reason for the change. Philip C. Gunion, Sales Manager of this company, said in a recent interview:

"The primary reason for changing our name was that we were constantly being confused with two other electrical manufacturers of similar name, one of which is owned by a competitive organization. Mail, telegrams, freight notices, etc., intended for the other two companies were frequently received by us, and vice versa.

"As there has been no Mr. Cutter connected with our company for over twenty-five years there was no reason not to change. Fortunately, the name of our product, the I-T-E Circuit Breaker, was as well known as our company name, and perhaps better known, so using the product name as a company name gives us a fully descriptive name that cannot be confused with the name of any other company.

"It is, I agree, a radical move to change a name of forty years' standing, but our new name has met with the unanimous approval of everybody in the electrical industry from whom we have had comments.

"The policies, personnel and products of the I-T-E Circuit Breaker Company are identical with those of the old company—nothing has been changed except the name.

"We hope by the change to secure all the advantages that came to the Mint Products Company when they changed their name to Life Savers, Inc."

Allis-Chalmers Mfg. Co., Milwaukee, Wis., has just issued a new bulletin, 1118-E, covering Types "AR" and "ARY" Polyphase Induction Motors which are our squirrel cage and slip ring type general purpose motors. This bulletin describes both the slip and roller bearing types and in standard horizontal and vertical construction.

Standard Underground Cable Company, Division of General Cable Corporation has recently made the following changes in its General Sales organization:

Mr. A. B. Saurman, formerly vice president and general sales manager has been made vice president and consulting general sales manager and will continue his headquarters at the general offices in Pittsburgh, upon his return from the South where he has been for some time on account of ill-health.

Mr. Harold P. Childs has been made general sales manager. Mr. Childs started with the Westinghouse Machine Company in 1903, going through the gas engine, steam engine, and steam turbine departments. He then became engaged in sales in the Pittsburgh office. Later he came to New York. He was made manager of the Westinghouse Machine Company in charge of Philadelphia and Baltimore offices. From there he went with the International Motor Company as manager of their Philadelphia, Baltimore and Washington offices. He returned to Westinghouse Machine Company in 1913 as special representative of the Eastern district in charge of public utility work.

During the war he was abroad with the 23rd Engineers, A. E. F. Mr. Childs holds the rank of Major, Engineers Reserve Corps.

Shortly following the war and from 1921 to 1925, Mr. Childs was with the General Electric Company in the executive office under Mr. Anson Burchard, vice chairman of the board, and Mr. Lovejoy, vice president. In September, 1925, he joined the Servel Corporation as vice president in charge of sales and advertising. Mr. Childs' connection with the Standard Underground Cable Company became effective March 15.

Col. William Henry Morgan, president Morgan Engineering Co., Alliance, Ohio, and a pioneer in the electric traveling crane industry, died at Union Memorial Hospital, Baltimore, March 29, following an operation. He was 63 years of age. Colonel Morgan was born in Pittston, Pa., June 1, 1865. His parents moved to Alliance in 1871 where in that year his father, Thomas R. Morgan, Sr., founded the Morgan Engineering Co. to manufacture steel mill and handling equipment. After attending the Alliance High School and Mount Union College, Alliance, Colonel Morgan went into the Morgan plant and, after the death of his father in 1897, became president of the company. In 1888 he designed one of the first electric traveling cranes built by the Morgan company and also developed considerable other equipment. After he became president, he continued to spend much of his time in the engineering department designing mill equipment. He was active in the company until about two years ago, when poor health compelled him to give up most of his business duties. He was a member of the American Iron and Steel Institute and of the ((British) Iron and Steel Institute. He acquired the title of Colonel a number of years ago when he served on the staff of George K. Nash, governor of Ohio. He is survived by his widow and one son, William H. Morgan, Jr., the latter connected with the Morgan plant.

The Martindale Electric Co., 1256 West Fourth Street, Cleveland, Ohio, announce their new "Double Duty" Commutator Stones for touching up commutators and slip rings.

One end is made from their coarse (cutting) grade and the other end from their fine (finishing) grade.

These Stones are furnished in various sizes convenient for carrying in the pocket or tool kit.

The Delta-Star Electric Co., 2400 Block, Fulton Street, Chicago, Ill., have issued a new price list No. 1 describing and listing a new line of rigid stud compression type solderless connectors. These connectors are made in single and double bolt lug type for conductors from No. 6 to 500,000 c.m. They are furnished in Tee, Parallel and Cross Connector types.

Benjamin Electric Mfg. Co., 120-218 So. Sangamon St., Chicago, now manufactures a new compact and sturdy ball fixture aligner.

This new device is easily and quickly installed and is suitable for all industrial locations where the lighting fixtures are suspended directly from the outlet box.

Even on an installation where the slope is as great as 45° this aligner permits the fixture to hang plumb, and, in addition, because of the "ball and socket" design the fixture is protected against jars and shocks. Often this protective feature will prolong the life of the lamp and reduce upkeep expense.

The new water filtration plant of the City of Wenatchee, Wash., is described in a paper by Fred J. Sharkey, City Engineer, and S. DeMoss, Structural Engineer, which has been reprinted and is being distributed, by the De Laval Steam Turbine Co., of Trenton, N. J., builders of the pumping equipment. Water is taken from the Columbia River, which is subject to considerable fluctuations in level at this point, through an intake pier and is conducted to an electrically operated pumping plant and sedimentation basins and filters located on the river bank.

A contract amounting to $2,250,000, the largest single award ever made for a street lighting improvement, was received today by G. L. Tarlton from the City of St. Louis. The contract is the fourth to be awarded in connection with the city's $8,000,000 street lighting project. The Westinghouse Electric and Manufacturing Company will furnish the equipment.

The area to be lighted under the fourth contract includes the downtown district as well as a number of arterial thoroughfares which intersect the city. The equipment will include 4,500 hollowspun granite standards of special design which, on the major thoroughfares, will have a height of 24 feet and support twin lighting units. These standards will also support the trolley wires, thus allowing the removal of the unsightly steel poles which now disfigure the principal streets. Single light standards having a height of eighteen and thirteen feet, respectively, will be installed on the streets which carry lighter traffic.

Over a million feet of underground cable will be required to furnish energy to the lamps.

The installation of the new lighting system must be completed on December 8, 1928, according to the terms of the contract.

Due to the popularity of a new type of safety switch which is being made by the Trumbull-Vanderpoel Electric Manufacturing Company, Bantam, Connecticut, their Pittsburgh Sales Representatives, H. Lee Reynolds Company, have added to their sales force, Mr. J. P. Madden, who is quite well known by the steel mill engineers. The chief characteristics of this switch are that it uses a multiple break principle and has eliminated a hinged contact. These two advantages have added materially to the life of the switch. Bulletins have been printed and mailed to a number of engineers, and additional copies can be had by addressing H. Lee Reynolds Company, 2548 Oliver Building, Pittsburgh.

BLISS CONTINUOUS NUT STOCK MILL

Built for cold rolling in one pass, direct from pickled rods, the various rectangular and hexigon shapes, used by the Bolt and Nut Trade.

Capacity of mill shown ¾" wide and under. Speed 200 to 400 feet per minute. Mills can be built for any size of stock.

Mills driven by adjustable speed motors and arranged for Clark patent system of control.

E. W. BLISS CO. BROOKLYN, N.Y. SALEM, OHIO.